Retrospective Study

Effect of obesity on post-operative outcomes following colorectal cancer surgery

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Abstract

BACKGROUND

Colorectal cancer (CRC) resection is currently being undertaken in an increasing number of obese patients. Existing studies have yet to reach a consensus as to whether obesity affects post-operative outcomes following CRC surgery.

AIM

To evaluate the post-operative outcomes of obese patients following CRC resection, as well as to determine the post-operative outcomes of obese patients in the subgroup undergoing laparoscopic surgery.

METHODS

Six-hundred and fifteen CRC patients who underwent surgery at the Prince Charles Hospital between January 2010 and December 2020 were categorized into two groups based on body mass index (BMI): Obese [BMI ≥ 30, n = 182 (29.6%)] and non-obese [BMI < 30, n = 433 (70.4%)]. Demographics, comorbidities, surgical features, and post-operative outcomes were compared between both groups. Post-operative outcomes were also compared between both groups in the subgroup of patients undergoing laparoscopic surgery [n = 472: BMI ≥ 30, n = 136 (28.8%); BMI
RESULTS
Obese patients had a higher burden of cardiac (73.1% vs 56.8%; \( P < 0.001 \)) and respiratory comorbidities (37.4% vs 26.8%; \( P = 0.01 \)). Obese patients were also more likely to undergo conversion to an open procedure (12.8% vs 5.1%; \( P = 0.002 \)), but did not experience more post-operative complications (51.6% vs 44.1%; \( P = 0.06 \)) or high-grade complications (19.2% vs 14.1%; \( P = 0.11 \)). In the laparoscopic subgroup, however, obesity was associated with a higher prevalence of post-operative complications (47.8% vs 39.3%; \( P = 0.05 \)) but not high-grade complications (17.6% vs 11.0%; \( P = 0.07 \)).

CONCLUSION
Surgical resection of CRC in obese individuals is safe. A higher prevalence of post-operative complications in obese patients appears to only be in the context of laparoscopic surgery.

Key Words: Colorectal cancer; Obesity; Body mass index; Post-operative outcomes; Clavien-Dindo

INTRODUCTION
Colorectal cancer (CRC) contributes substantially to the healthcare burden worldwide[1], and is the fourth most commonly diagnosed malignancy and second most common cause of cancer-related death in Australia[2]. Obesity is a rising global pandemic associated with systemic disease and poor health outcomes[3]. Body mass index (BMI) is an overall measure of total body fat, and is an easily calculable and accepted surrogate marker of obesity[4]. The World Health Organization (WHO) defines obesity in adults as a BMI of ≥ 30 kg/m²[5].

The increasing prevalence of obesity is of particular concern to colorectal surgeons, as it is not only implicated in the pathogenesis of CRC but also may have an impact on post-operative outcomes[6]. However, with several studies reporting inconsistent findings[7-9], there remains no consensus. The Clavien-Dindo Classification is a standardized system of grading post-operative complications, ranging from grade I (minor events) to grade V (death)[10]. With objective criteria, it is a highly reproducible method of grading post-operative complications, and is validated across several surgical disciplines including colorectal surgery[11].

In this study, we conducted a retrospective cohort study to outline and compare the clinical characteristics of obese and non-obese patients undergoing surgical resection of CRC at our institution, as well as to evaluate the impact of obesity on post-operative outcomes using the Clavien-Dindo Classification of Surgical Complications. The secondary aim was to determine the impact of obesity on post-operative outcomes in the subgroup of patients undergoing laparoscopic CRC resection.

MATERIALS AND METHODS

Study design
The Prince Charles Hospital (TPCH) CRC Database includes all patients who have undergone CRC surgery.
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Table 1 Demographic and co-morbidity characteristics of patients undergoing colorectal cancer surgery

|                        | BMI < 30 (% of group) | BMI ≥ 30 (% of group) | Total | P value |
|------------------------|-----------------------|-----------------------|-------|---------|
| **Patients**           | 433                   | 182                   | 615   |         |
| **Age**                | 71 (58.0-79.0)        | 70 (60.0-77.0)        | 0.45  |         |
| **Sex**                |                       |                       |       |         |
| Male                   | 232 (53.6)            | 83 (45.6)             | 315   | 0.08    |
| Female                 | 201 (46.4)            | 99 (54.4)             | 300   |         |
| **ASA grade**          |                       |                       |       |         |
| Low (ASA 1-2)          | 198 (45.7)            | 54 (29.7)             | 252   | < 0.001 |
| High (ASA ≥ 3)         | 235 (54.3)            | 128 (70.3)            | 363   |         |
| **Any cardiac comorbidity** | 246 (56.8)      | 133 (73.1)            | 379   | < 0.001 |
| **Specified cardiac comorbidity** |               |                       |       |         |
| Ischemic heart disease | 79 (18.2)             | 37 (20.3)             | 116   | 0.57    |
| Coronary artery bypass graft | 25 (5.8)                | 16 (8.8)              | 41    | 0.21    |
| Coronary stents        | 25 (5.8)              | 15 (8.2)              | 40    | 0.28    |
| Pacemaker              | 8 (1.8)               | 5 (2.7)               | 13    | 0.54    |
| Valve replacement      | 19 (4.4)              | 4 (2.2)               | 23    | 0.25    |
| Heart failure          | 19 (4.4)              | 9 (4.9)               | 28    | 0.83    |
| Hypertension           | 186 (43.0)            | 117 (64.3)            | 303   | < 0.001 |
| Atrial fibrillation    | 54 (12.5)             | 29 (15.9)             | 83    | 0.25    |
| **Any respiratory comorbidity** | 116 (26.8)          | 68 (37.4)             | 184   | 0.01    |
| **Specified respiratory comorbidity** |           |                       |       |         |
| Asthma                 | 41 (9.5)              | 27 (14.8)             | 68    | 0.07    |
| Chronic obstructive pulmonary disease | 52 (12.0)         | 20 (11.0)             | 72    | 0.78    |
| Bronchiectasis         | 6 (1.4)               | 3 (1.6)               | 9     | 0.73    |
| Obstructive sleep apnea| 10 (2.3)              | 26 (14.3)             | 36    | < 0.001 |
| **Any metabolic comorbidity** | 156 (36.5)        | 182 (100.0)           | 340   | < 0.001 |
| **Specified metabolic comorbidity** |              |                       |       |         |
| Type 1 diabetes mellitus | 3 (0.7)                 | 0 (0.0)               | 3     | 0.56    |
| Type 2 diabetes mellitus | 55 (12.7)               | 52 (28.6)             | 107   | < 0.001 |
| Hyperlipidemia         | 116 (26.8)            | 59 (32.4)             | 175   | 0.17    |
| **Current smoker**     | 67 (15.5)             | 25 (13.8)             | 92    | 0.71    |
| **Alcohol > 2 standard drinks/d** | 44 (10.2)             | 13 (7.1)              | 57    | 0.29    |

ASA: American Society of Anesthesiologists; BMI: Body mass index.

resection at our institution. The criteria for inclusion in TPCH CRC Database were all patients who had histologically confirmed CRC (including appendiceal cancers as per the International Classification of Diseases-10 classification) and underwent an operation at TPCH between January 2010 and December 2020. As per the WHO definition, patients were grouped into an obese group (BMI ≥ 30) or non-obese group (BMI < 30), and the demographic features, comorbidities, and surgical features in each group were reported and compared. In addition, the post-operative outcomes of patients in each group were also compared.

**Ethics approval**

Approval for the TPCH Colorectal Cancer Database was granted by TPCH Human Research Ethics Committee (HREC/17/QPCH/295).

**Demographics and comorbidities**

Demographic data documented in this study included age, sex, BMI, smoking, and alcohol status. Patient comorbidities were categorized into cardiac, respiratory and metabolic etiologies, with specific diseases recorded in each category if present. The American Society of Anesthesiologists (ASA) grade was also recorded (Table 1).
## Table 2 Surgical features of patients undergoing colorectal cancer surgery

|                          | BMI < 30 (% of group) | BMI ≥ 30 (% of group) | Total | P value |
|--------------------------|------------------------|------------------------|-------|---------|
| Patients                 | 433                    | 182                    | 615   |         |
| Cancer location          |                        |                        |       |         |
| Appendix                 | 37 (8.5)               | 9 (4.9)                | 46    | 0.47    |
| Cecum to transverse colon| 205 (47.3)             | 92 (50.5)              | 297   |         |
| Splenic flexure to sigmoid colon | 143 (33.0) | 61 (33.5) | 204 |         |
| Rectum                   | 48 (11.1)              | 20 (11.0)              | 68    |         |
| Operative urgency        |                        |                        |       |         |
| Elective                 | 359 (82.9)             | 161 (88.5)             | 519   | 0.09    |
| Emergency                | 74 (17.1)              | 21 (11.5)              | 95    |         |
| Operative approach       |                        |                        |       |         |
| Laparoscopic             | 265 (61.5)             | 96 (53.3)              | 361   | 0.002   |
| Open                     | 72 (16.7)              | 20 (11.1)              | 92    |         |
| Laparoscopic-assisted    | 71 (16.5)              | 40 (22.2)              | 111   |         |
| Laparoscopic converted to open | 22 (5.1) | 23 (12.8) | 45  |         |
| Transanal excision       | 1 (0.2)                | 1 (0.2)                | 2     |         |
| Operation performed      |                        |                        |       |         |
| Appendicectomy           | 31 (7.2)               | 8 (4.4)                | 39    | 0.18    |
| Right hemicolectomy      | 170 (39.3)             | 74 (40.7)              | 244   |         |
| Extended right hemicolectomy | 34 (7.9) | 18 (9.9) | 52  |         |
| Left hemicolectomy       | 18 (4.2)               | 11 (6.0)               | 29    |         |
| Hartmann’s procedure     | 20 (4.6)               | 5 (2.7)                | 25    |         |
| High anterior resection  | 76 (17.6)              | 37 (20.3)              | 113   |         |
| Low anterior resection   | 27 (6.2)               | 9 (4.9)                | 36    |         |
| Ultra-low anterior resection | 28 (6.5) | 5 (2.7) | 33  |         |
| Other                    | 29 (6.7)               | 15 (8.2)               | 44    |         |
| Stoma requirement        | 65 (15.0)              | 18 (9.9)               | 83    | 0.09    |
| Peri-operative transfusion requirement | 65 (15.0) | 28 (15.4) | 93  | 0.90    |

BMI: Body mass index.

### Surgical features

Surgical features recorded included cancer location, operative urgency, operative approach, colorectal operation performed, requirement for stoma, and peri-operative requirement for transfusion (Table 2).

### Post-operative outcomes

Post-operative outcomes recorded included the occurrence of any post-operative complication, which were each graded by the Clavien-Dindo Classification of Surgical Complications (Supplementary material). Complications were also classified as either no complication/low-grade and high-grade, defined as Clavien-Dindo grades I-II and III-V respectively. In addition, complications were attributed to either a surgical or medical cause, with specific surgical and medical complications also recorded if they occurred (Table 3).

The outcomes as above were also undertaken in the subgroup of patients undergoing laparoscopic surgery (Table 4). Patients who underwent laparoscopic surgery who were converted to an open procedure intra-operatively were excluded from this subgroup. Furthermore, post-operative outcomes of obese vs non-obese patients were compared in subgroups divided by cancer location. Patients were divided into a right sided colon cancer (caecum to transverse colon) subgroup (Table 5), left sided colon cancer (splenic flexure to sigmoid colon) subgroup (Table 6) and a rectal cancer subgroup (Table 7).

### Statistical analysis

Statistical analysis was performed using Stata v17 (StataCorp, La Jolla, CA, United States). Categorical variables are presented as frequencies, and continuous variables are presented as medians and interquartile ranges. Groups were assessed using the t-test, χ² test or Fisher’s exact test as appropriate. Statistically significant results were defined as P ≤ 0.05.
### Table 3 Post-operative outcomes of patients undergoing colorectal cancer surgery

| Post-operative complication (CD grade) | BMI < 30 (% of group) | BMI ≥ 30 (% of group) | Total | P value |
|----------------------------------------|-----------------------|-----------------------|-------|---------|
| No complication                        | 242 (55.9)            | 88 (48.4)             | 330   | 0.06    |
| Complication                           | 191 (44.1)            | 94 (51.6)             | 285   |         |
| I                                      | 31 (7.2)              | 17 (9.3)              | 48    |         |
| II                                     | 99 (22.9)             | 42 (23.1)             | 141   |         |
| IIIa                                   | 27 (6.2)              | 15 (8.2)              | 42    |         |
| IIIb                                   | 13 (3.0)              | 6 (3.3)               | 19    |         |
| IVa                                    | 13 (3.0)              | 10 (5.5)              | 23    |         |
| IVb                                    | 0 (0.0)               | 3 (1.6)               | 3     |         |
| V                                      | 8 (1.8)               | 1 (0.5)               | 9     |         |
| No complication or low-grade complication (CD I-II) | 372 (85.9) | 147 (80.8) | 519 | 0.11    |
| High-grade complication (CD IIIa-V)    | 61 (14.1)             | 35 (19.2)             | 96    |         |
| Any surgical complication              | 99 (22.9)             | 48 (26.4)             | 147   | 0.35    |
| Specified surgical complications       | Abdomino-pelvic collection | 16 (3.7) | 3 (1.6) | 19 | 0.21    |
|                                        | Anastomotic leak      | 12 (2.8)              | 7 (3.8) | 19 | 0.46    |
|                                        | Wound infection       | 19 (4.4)              | 7 (3.8) | 26 | 0.83    |
|                                        | Prolonged ileus       | 49 (11.3)             | 27 (14.8) | 76 | 0.23    |
|                                        | Post-operative hemorrhage | 3 (0.7) | 2 (1.1) | 5 | 0.64    |
|                                        | Return to theatre     | 13 (3.0)              | 7 (3.8) | 20 | 0.62    |
|                                        | Post-operative sepsis | 16 (8.3)              | 8 (8.6) | 24 | 1.00    |
| Any medical complication               | 96 (22.2)             | 37 (20.3)             | 133   | 0.67    |
| Specified medical complications        | VTE (DVT/PE)          | 4 (0.9)               | 2 (1.3) | 6 | 1.00    |
|                                        | Pneumonia             | 19 (4.4)              | 8 (4.4) | 27 | 1.00    |
|                                        | Ischemic cardiac event| 5 (1.2)               | 5 (2.7) | 10 | 0.17    |
|                                        | Cardiac arrhythmia    | 30 (6.9)              | 9 (4.9) | 39 | 0.47    |
|                                        | Respiratory failure   | 10 (2.3)              | 8 (4.4) | 18 | 0.19    |
|                                        | Renal failure         | 12 (2.8)              | 7 (3.8) | 19 | 0.46    |
|                                        | Unplanned ICU admission | 16 (3.7) | 6 (3.3) | 22 | 1.00    |
| Post-operative length of stay (d)      | 6 (IQR 5-11)          | 7 (IQR 5-11)          |       | 0.42    |

BMI: Body mass index; CD: Clavien-Dindo; DVT: Deep vein thrombosis; ICU: Intensive care unit; IQR: Interquartile range; PE: Pulmonary embolism; VTE: Venous thrombo-embolism.

**RESULTS**

**Patient demographics and comorbidities**

From January 2010 to December 2020, 615 patients at our institution fulfilled the inclusion criteria and were included in the database. In all, 182 patients (29.6%) had a BMI ≥ 30 (obese group), and 433 patients (70.4%) had a BMI < 30 (non-obese group). Table 1 outlines and compares the demographic features and comorbidities in both groups.

Patients in both groups were of similar age (obese group, 70 years vs non-obese group, 71 years; P = 0.45) and sex (45.6% male vs 53.6% male; P = 0.08). By contrast, the obese group had a greater proportion of patients graded at a higher ASA grade (ASA I-II: 29.7% vs 45.7%, ASA ≥ III: 70.3% vs 54.3%; P < 0.001), and also had a higher prevalence of cardiac comorbidities (73.1% vs 56.8%; P < 0.001) and respiratory comorbidities (37.4% vs 26.8%; P = 0.01) compared to patients in the non-obese group. Obese
Table 4 Post-operative outcomes in the subgroup of patients undergoing laparoscopic colorectal cancer surgery

|                          | BMI < 30 (% of group) | BMI ≥ 30 (% of group) | Total | P value |
|--------------------------|-----------------------|-----------------------|-------|---------|
| Patients                 | 336                   | 136                   | 472   |         |
| Post-operative complication (CD grade) |                      |                       |       |         |
| No complication          | 204 (60.7)            | 71 (52.2)             | 275   | 0.05    |
| Complication             | 132 (39.3)            | 65 (47.8)             | 197   |         |
| I                        | 24 (7.1)              | 12 (8.8)              | 36    |         |
| II                       | 71 (21.1)             | 29 (21.3)             | 100   |         |
| IIIa                     | 20 (6.0)              | 10 (7.4)              | 30    |         |
| IIIb                     | 6 (1.8)               | 6 (4.4)               | 12    |         |
| IVa                      | 6 (1.8)               | 6 (4.4)               | 12    |         |
| IVb                      | 0 (0.0)               | 2 (1.5)               | 2     |         |
| V                        | 5 (1.5)               | 0 (0.0)               | 5     |         |
| No complication or low-grade complication (CD I-II) | 299 (89.0)            | 112 (82.4)            | 411   | 0.07    |
| High-grade complication (CD IIIa-V) | 37 (11.0)            | 24 (17.6)             | 61    |         |
| Any surgical complication | 68 (20.2)             | 37 (27.2)             | 105   | 0.11    |
| Specified surgical complications | 9 (2.7)               | 3 (2.2)               | 12    | 1.00    |
| Abdomino-pelvic collection | 7 (2.1)               | 5 (3.7)               | 12    | 0.34    |
| Anastomotic leak         | 13 (3.9)              | 6 (4.4)               | 19    | 0.80    |
| Wound infection          | 33 (9.8)              | 21 (15.4)             | 54    | 0.11    |
| Prolonged ileus          | 2 (0.6)               | 1 (0.7)               | 3     | 1.00    |
| Post-operative hemorrhage | 6 (1.8)               | 6 (4.4)               | 12    | 0.11    |
| Return to theatre        | 12 (9.0)              | 4 (6.2)               | 16    | 0.59    |
| Any medical complication | 66 (19.6)             | 21 (15.4)             | 87    | 0.36    |
| Specified medical complications | 3 (0.9)               | 1 (0.7)               | 4     | 1.00    |
| VTE (DVT/PE)             | 13 (3.9)              | 2 (1.5)               | 15    | 0.25    |
| Pneumonia                | 3 (0.9)               | 3 (2.2)               | 6     | 0.36    |
| Ischemic cardiac event   | 23 (6.8)              | 7 (5.1)               | 30    | 0.68    |
| Cardiac arrhythmia       | 7 (2.1)               | 6 (4.4)               | 13    | 0.21    |
| Respiratory failure      | 7 (2.1)               | 4 (2.9)               | 11    | 0.52    |
| Renal failure            | 6 (1.8)               | 3 (2.2)               | 9     | 0.72    |
| Post-operative length of stay (d) | 6 (IQR 4-9)          | 6 (IQR 5-10)          | 0.15  |         |

BMI: Body mass index; CD: Clavien-Dindo; DVT: Deep vein thrombosis; ICU: Intensive care unit; IQR: Interquartile range; PE: Pulmonary embolism; VTE: Venous thrombo-embolism.

patients were more likely to have type II diabetes mellitus (28.6% vs 12.7%; P < 0.001).

Surgical features

Table 2 outlines and compares the surgical features between the obese and non-obese groups. Both groups had a similar proportion of elective and emergency procedures (88.5% vs 82.9% and 11.5% vs 17.1% respectively; P = 0.09). The obese group had a higher proportion of patients requiring conversion to an open procedure (12.8% vs 5.1%; P = 0.002). Both groups had a similar percentage of patients requiring peri-operative blood transfusion (15.4% vs 15.0%; P = 0.90).

Post-operative outcomes

Table 3 outlines and compares the post-operative outcomes and complications between the obese and non-obese groups. There were no significant differences between groups in terms of the prevalence of
### Table 5 Post-operative outcomes in the subgroup of patients with right sided colon cancer

| BMI < 30 (% of group) | BMI ≥ 30 (% of group) | Total | P value |
|-----------------------|-----------------------|-------|---------|
| **Patients**          |                       |       |         |
| 205                   | 92                    | 297   |         |
| **Post-operative complication (CD grade)** |                       |       |         |
| No complication       | 94 (45.9)             | 44 (47.8) | 138 | 0.61 |
| Complication          | 111 (54.1)            | 48 (52.2) | 159 |       |
| I                     | 21 (10.2)             | 9 (9.8) | 30 |       |
| II                    | 58 (28.3)             | 23 (25.0) | 81 |       |
| IIIa                  | 19 (9.3)              | 7 (7.6) | 26 |       |
| IIIb                  | 3 (1.5)               | 1 (1.1) | 4 |       |
| IVa                   | 8 (3.9)               | 5 (5.4) | 13 |       |
| IVb                   | 0 (0.0)               | 2 (2.2) | 2 |       |
| V                     | 2 (1.0)               | 1 (1.1) | 3 |       |
| No complication or low-grade complication (CD I-II) | 173 (84.4) | 76 (82.6) | 249 | 0.73 |
| High-grade complication (CD IIIa-V) | 32 (15.6) | 16 (17.4) | 48 |       |
| **Any surgical complication** | 52 (25.4) | 22 (23.9) | 74 | 0.88 |
| **Specified surgical complications** |                       |       |         |
| Abdomino-pelvic collection | 7 (3.4) | 3 (0.0) | 10 | 0.10 |
| Anastomotic leak       | 7 (3.4)               | 0 (0.0) | 7 | 1.00 |
| Wound infection        | 10 (4.9)              | 3 (3.3) | 13 | 0.76 |
| Prolonged ileus        | 26 (12.7)             | 14 (15.2) | 40 | 0.58 |
| Post-operative hemorrhage | 1 (0.5) | 2 (2.2) | 3 | 0.23 |
| Return to theatre      | 3 (1.5)               | 1 (1.1) | 4 | 1.00 |
| Post-operative sepsis  | 2 (1.0)               | 1 (1.1) | 3 | 1.00 |
| **Any medical complication** | 55 (26.8) | 25 (27.2) | 80 | 1.00 |
| **Specified medical complications** |                       |       |         |
| VTE (DVT/PE)           | 2 (1.0)               | 1 (1.1) | 3 | 1.00 |
| Pneumonia              | 14 (6.8)              | 6 (6.5) | 20 | 1.00 |
| Ischemic cardiac event | 2 (1.0)               | 3 (3.3) | 5 | 0.17 |
| Cardiac arrhythmia     | 20 (9.8)              | 6 (6.5) | 26 | 0.51 |
| Respiratory failure    | 4 (2.0)               | 5 (5.4) | 9 | 0.14 |
| Renal failure          | 7 (3.4)               | 6 (6.5) | 13 | 0.23 |
| Unplanned ICU admission| 8 (3.9)               | 4 (4.3) | 12 | 1.00 |
| **Post-operative length of stay (d)** | 7 (IQR 5-11) | 6 (IQR 5-11) | 0.91 |       |

BMI: Body mass index; CD: Clavien-Dindo; DVT: Deep vein thrombosis; IQR: Interquartile range; PE: Pulmonary embolism; VTE: Venous thromboembolism.

Post-operative complications (51.6% vs 44.1%; P = 0.06) or high-grade complications (19.2% vs 14.1%; P = 0.11). In-hospital mortality (Clavien-Dindo V) occurred in 1 obese patient (0.5%) and 8 non-obese patients (1.8%). There were no differences between both groups in the incidence of surgical complications (26.4% vs 22.9%; P = 0.35), including, but not limited to, anastomotic leak (3.8% vs 2.8%; P = 0.46), wound infection (3.8% vs 4.4%; P = 0.83) and return to theatre (3.8% vs 3.0%; P = 0.62). The prevalence of post-operative medical complications was also similar between both groups (20.3% vs 22.2%; P = 0.67), and there were no differences in the prevalence of specific medical complications. The median post-operative length of stay was also similar between both groups (7 d vs 6 d; P = 0.42).

**Post-operative outcomes in patients undergoing laparoscopic surgery**

A total of 472 patients (76.7%) underwent laparoscopic and laparoscopic-assisted surgery; among them, 336 (71.2%) had a BMI < 30, and 136 (28.8%) had a BMI ≥ 30. Obese patients in the laparoscopic surgery
Table 6 Post-operative outcomes in the subgroup of patients with left sided colon cancer

| Patients | BMI < 30 (% of group) | BMI ≥ 30 (% of group) | Total | P value |
|----------|-----------------------|-----------------------|-------|---------|
| Post-operative complication (CD grade) | | | | |
| No complication | 90 (62.9) | 32 (52.5) | 122 | 0.09 |
| Complication | 53 (37.1) | 29 (47.5) | 82 | |
| I | 7 (4.9) | 6 (9.8) | 13 | |
| II | 32 (22.4) | 12 (19.7) | 44 | |
| IIIa | 3 (2.1) | 6 (9.8) | 9 | |
| IIIb | 5 (3.5) | 2 (3.3) | 7 | |
| IVa | 3 (2.1) | 2 (3.3) | 5 | |
| IVb | 0 (0.0) | 1 (1.6) | 1 | |
| V | 3 (2.1) | 0 (0.0) | 3 | |
| No complication or low-grade complication (CD I-II) | 129 (90.2) | 50 (82.0) | 179 | 0.11 |
| High-grade complication (CD IIIa-V) | 14 (9.8) | 11 (18.0) | 25 | |
| Any surgical complication | 29 (20.3) | 17 (27.9) | 46 | 0.27 |
| Specified surgical complications | | | | |
| Abdomino-pelvic collection | 7 (4.9) | 2 (3.3) | 9 | 0.73 |
| Anastomotic leak | 4 (2.8) | 2 (3.3) | 6 | 1.00 |
| Wound infection | 4 (2.8) | 3 (4.9) | 7 | 0.43 |
| Prolonged ileus | 17 (11.9) | 9 (14.8) | 26 | 0.65 |
| Post-operative hemorrhage | 1 (0.7) | 0 (0.0) | 1 | 1.00 |
| Return to theatre | 5 (3.5) | 3 (4.9) | 8 | 0.70 |
| Post-operative sepsis | 3 (2.1) | 0 (0.0) | 3 | 0.56 |
| Any medical complication | 28 (19.6) | 6 (9.8) | 34 | 0.10 |
| Specified medical complications | | | | |
| VTE (DVT/PE) | 1 (0.7) | 1 (1.6) | 2 | 0.51 |
| Pneumonia | 5 (3.5) | 2 (3.3) | 7 | 1.00 |
| Ischemic cardiac event | 1 (0.7) | 0 (0.0) | 1 | 1.00 |
| Cardiac arrhythmia | 6 (4.2) | 0 (0.0) | 6 | 1.00 |
| Respiratory failure | 4 (2.8) | 2 (3.3) | 6 | 1.00 |
| Renal failure | 4 (2.8) | 0 (0.0) | 4 | 0.32 |
| Unplanned ICU admission | 5 (3.5) | 2 (3.3) | 7 | 1.00 |
| Post-operative length of stay (d) | 7 (IQR 5-10) | 7 (IQR 5-10) | | 0.89 |

BMI: Body mass index; CD: Clavien-Dindo; DVT: Deep vein thrombosis; IQR: Interquartile range; PE: Pulmonary embolism; VTE: Venous thromboembolism.

subgroup similarly had a higher ASA grade (ASA I-II: 36.8% vs 48.1%; ASA ≥ III: 63.2% vs 51.9%; P = 0.03), and a higher prevalence of pre-existing cardiac comorbidities (72.8% vs 56.3%; P < 0.001) and respiratory comorbidities (38.2% vs 26.9%; P = 0.02) compared to non-obese patients.

Post-operative outcomes of the patients in the cohort undergoing laparoscopic surgery are shown in Table 4. Obese patients were more likely to experience a post-operative complication (47.8% vs 39.3%; P = 0.05); however, there was no differences between both groups in the incidence of high-grade complications (17.6% vs 11.0%; P = 0.07). There were similarly no major differences between both groups in the percentage of patients who experienced a surgical complication (27.2% vs 20.2%; P = 0.11) or medical complication (15.4% vs 19.6%; P = 0.36). The median post-operative length of stay was equivalent between both groups (6 d vs 6 d; P = 0.15).
## Table 7 Post-operative outcomes in the subgroup of patients with rectal cancer

|                          | BMI < 30 (% of group) | BMI ≥ 30 (% of group) | Total | \( P \) value |
|--------------------------|-----------------------|-----------------------|-------|---------------|
| **Patients**             | 48                    | 20                    | 68    |               |
| **Post-operative (CD grade)** |                       |                       |       |               |
| No complication          | 22 (45.8)             | 6 (30.0)              | 28    | 0.68          |
| Complication             | 26 (54.2)             | 14 (70.0)             | 40    |               |
| I                        | 3 (6.3)               | 2 (10.0)              | 5     |               |
| II                       | 8 (16.7)              | 5 (25.0)              | 13    |               |
| IIIa                     | 5 (10.4)              | 2 (10.0)              | 7     |               |
| IIIb                     | 5 (10.4)              | 3 (15.0)              | 8     |               |
| IVa                      | 2 (4.2)               | 2 (10.0)              | 4     |               |
| IVb                      | 0 (0.0)               | 0 (0.0)               | 0     |               |
| V                        | 3 (6.3)               | 0 (0.0)               | 3     |               |
| No complication or low-grade complication (CD I-II) | 33 (68.8)             | 13 (65.0)             | 46    | 0.78          |
| High-grade complication (CD IIIa-V) | 15 (31.2)             | 7 (35.0)              | 22    |               |
| **Any surgical complication** | 18 (37.5)             | 7 (35.0)              | 25    | 1.00          |
| **Specified surgical complications** |                   |                       |       |               |
| Abdomino-pelvic collection | 2 (4.2)               | 1 (5.0)               | 3     | 1.00          |
| Anastomotic leak         | 1 (2.1)               | 2 (10.0)              | 3     | 0.20          |
| Wound infection          | 5 (10.4)              | 0 (0.0)               | 5     | 0.31          |
| Prolonged ileus          | 6 (12.5)              | 3 (15.0)              | 9     | 1.00          |
| Post-operative hemorrhage | 1 (2.1)               | 0 (0.0)               | 1     | 1.00          |
| Return to theatre        | 5 (10.4)              | 3 (15.0)              | 8     | 0.68          |
| Post-operative sepsis    | 1 (2.1)               | 0 (0.0)               | 1     | 1.00          |
| **Any medical complication** | 13 (27.1)             | 5 (25.0)              | 18    | 1.00          |
| **Specified medical complications** |                   |                       |       |               |
| VTE (DVT/PE)             | 1 (2.1)               | 0 (0.0)               | 1     | 1.00          |
| Pneumonia                | 0 (0.0)               | 0 (0.0)               | 0     |               |
| Ischemic cardiac event   | 2 (4.2)               | 2 (10.0)              | 4     | 0.58          |
| Cardiac arrhythmia       | 4 (8.3)               | 2 (10.0)              | 6     | 1.00          |
| Respiratory failure      | 2 (4.2)               | 1 (5.0)               | 3     | 1.00          |
| Renal failure            | 1 (2.1)               | 1 (5.0)               | 2     | 0.50          |
| Unplanned ICU admission  | 3 (6.3)               | 0 (0.0)               | 3     | 0.35          |
| **Post-operative length of stay (d)** | 9 (IQR 6-14)          | 10 (IQR 5-21)         | 0.91  |               |

BMI: Body mass index; CD: Clavien-Dindo; DVT: Deep vein thrombosis; IQR: Interquartile range; PE: Pulmonary embolism; VTE: Venous thromboembolism.

### Post-operative outcomes of obese vs non-obese patients based on cancer location

Obese and non-obese patients in the right-sided colon cancer subgroup had equivalent outcomes, with no differences in the incidence of post-operative complications (52.2% vs 54.1%; \( P = 0.61 \)), high-grade complications (17.4% vs 15.6%; \( P = 0.73 \)), surgical complications (23.9% vs 25.4%; \( P = 0.88 \)), or medical complications (27.2% vs 26.8%; \( P = 1.00 \)). Similarly in the left-sided colon cancer subgroup there were no differences between obese and non-obese patients in the percentage of post-operative complications (47.5% vs 37.1%; \( P = 0.09 \)), high-grade complications (18.0% vs 9.8%; \( P = 0.11 \)), surgical complications (27.9% vs 20.3%; \( P = 0.27 \)), or medical complications (9.8% vs 19.6%; \( P = 0.10 \)). In the rectal cancer subgroup, there were also no differences between obese and non-obese patients in the prevalence of post-operative complications (70.0% vs 54.2%; \( P = 0.68 \)), high-grade complications (35.0% vs 31.2%; \( P = 0.78 \)), surgical complications (35.0% vs 37.5%; \( P = 1.00 \)), or medical complications (25.0% vs 27.1%; \( P = 1.00 \)).
We found that despite obese patients with an obese BMI having significantly higher rates of cardiac comorbidities, respiratory comorbidities, Type II diabetes mellitus, and conversion to open surgery compared to patients with a non-obese BMI, there was no increased prevalence of post-operative complications (51.6% vs 44.1%; \( P = 0.06 \)) or high-grade complications (19.2% vs 14.1%; \( P = 0.11 \)) following CRC surgery. Our findings are concordant with Genser et al\[12\], who reported that in patients undergoing emergency colon cancer surgery, obese patients did not experience a higher proportion of post-operative complications (54% vs 52%; \( P = 0.86 \)) or high-grade complications (20% vs 17%; \( P = 0.47 \)). Despite our obese cohort having a higher burden of medical comorbidities, we did not observe an increased rate of specific post-operative medical complications. Smith et al\[13\] also showed that obese patients are not at an increased risk of post-operative pneumonia or renal failure, and Merkow et al\[14\] showed that obese patients are similarly not at increased risk of post-operative complications, cardiac arrest, myocardial infarction, or stroke. Obesity may not be an independent predictor of peri-operative cardiac complications, with the latter more accurately related to functional status rather than traditional cardiovascular risk factors\[15\].

Importantly, we determined that the impact of obesity on post-operative outcomes may only manifest in patients undergoing laparoscopic resection, with obese patients in this subgroup having a significantly increased prevalence of post-operative complications (47.8% vs 39.3%; \( P = 0.05 \)). It should be noted that these findings were not influenced by patients who underwent laparoscopic converted to open surgery given that they were excluded from this subgroup.

In contrast to our findings, a Chinese study by Xia et al\[16\] reported that following laparoscopic CRC resection, patients with a BMI ≥ 30 had a higher but non-significant incidence of Clavien-Dindo grade III complications compared to patients with a BMI < 25 (14.3% vs 5.1%; \( P = 0.178 \)). Similarly, a Korean study on laparoscopic CRC outcomes by Park et al\[17\] also showed that obesity was not associated with an increased rate of major post-operative complications including ileus, bleeding and anastomotic leak (7.4% vs 5.3%; \( P = 0.889 \)). Non-significant results in both these studies may be related to the lower prevalence of obesity in Asian countries, which is reflected by both studies having only 2.7% of their cohorts categorized as BMI ≥ 30. Two systematic reviews of laparoscopic CRC surgery outcomes in the obese by Fung et al\[18\] and He et al\[19\] have both reported obesity to be associated with increased overall post-operative morbidity (odds ratio (OR) = 1.54, 95% confidence interval (CI): 1.21-1.97 and OR = 1.40, 95%CI: 1.18-1.66 respectively).

It is widely recognized that visceral obesity is associated with increased intra-operative technical difficulty by reducing access and visualization from thickened omentum and mesentery, distorting surgical planes, and increasing the risk of bleeding from both difficult mobilization of vessels and friable fatty tissue\[20\]. Our finding of poorer post-operative outcomes in obese patients undergoing laparoscopic surgery and not the obese cohort in general may be due to the fact that these aforementioned issues are aggravated in a laparoscopic approach, where increased intra-abdominal adiposity may severely restrict the already small working space available during a minimally-invasive resection. In addition, obese patients are pre-disposed to having a reduced physiologic reserve, and are thus at a greater risk of hemodynamic compromise during pneumoperitoneum from both increased intra-abdominal pressure and systemic acidosis secondary to carbon dioxide absorption\[21\].

In the modern era, laparoscopic surgery has been established as the standard of care in CRC surgery\[22\]. Although we have shown that utilizing this approach is associated with an increased prevalence of general post-operative complications in obese patients, we acknowledge that there are circumstances where the well-recognized benefits of laparoscopic surgery such as earlier restoration of gut motility, reduced post-operative pain and shorter length of stay may outweigh the perceived risks\[23,24\]. Martin and Stocchi\[25\] have proposed several practical strategies during laparoscopic colectomy in the obese such as the use of a 30-degree laparoscope to facilitate exposure and 10 mm instruments to allow for greater leverage during retraction, as well as the use of intra-corporeal vessel ligation given potential difficulties in exteriorizing thickened omentum. Surgeons attempting a laparoscopic approach in obese patients should be adequately experienced and aware that the benefits of laparoscopic surgery likely diminish if meaningful progress in the operation is not made.

We recognize that as an anthropometric measure, BMI has its limitations in the ability to identify visceral obesity, and also is distributed differently among ethnic groups\[26\]. Our rationale for using BMI as opposed to more specific volumetric measures of intra-abdominal adiposity such as visceral fat area, is that BMI is a much more commonly used definition of obesity in the literature. This enabled us to compare our outcomes directly against a larger number of studies. In addition, given that BMI is indicative of whole-body fat, it also allows for the analysis of general adipose-associated pathophysiological processes\[19\].

We found that despite patients with an obese BMI having significantly higher rates of cardiac comorbidities, respiratory comorbidities, Type II diabetes mellitus, and conversion to open surgery compared to patients with a non-obese BMI, there was no increased prevalence of post-operative complications (51.6% vs 44.1%; \( P = 0.06 \)) or high-grade complications (19.2% vs 14.1%; \( P = 0.11 \)) following CRC surgery.
CONCLUSION

Surgical resection of CRC in obese individuals is safe. A higher prevalence of post-operative complications in obese patients appears to only be in the context of laparoscopic surgery.

ARTICLE HIGHLIGHTS

Research background
Obesity is a worldwide epidemic of increasing significance. Although the colorectal surgeons of today manage a greater number of obese patients with colorectal cancer (CRC), the current literature reports inconsistent findings on whether this phenomenon impacts post-operative outcomes following CRC surgery.

Research motivation
This research was conducted to determine whether obese patients had equivalent outcomes compared to non-obese patients following CRC surgery. This is an important issue, as there is no consensus on whether obesity truly impacts post-operative outcomes, yet obese patients are at risk of having their surgery withheld or delayed based on this factor alone.

Research objectives
The primary aim of this study was to compare the post-operative outcomes of obese vs non-obese patients following CRC surgery. With laparoscopic surgery now recognized as the standard of care in CRC management, post-operative outcomes between obese and non-obese patients were also analyzed in the subgroup of patients undergoing laparoscopic CRC surgery.

Research methods
Patients who underwent CRC resection between January 2010 and December 2020 at the Prince Charles Hospital, Queensland, Australia were included in this study. As per the World Health Organization definition, this study defined obesity as a body mass index (BMI) ≥ 30 \( \text{kg/m}^2 \). Patients were divided into an obese and non-obese group, and post-operative outcomes were compared between these two groups using parametric and non-parametric tests. This study also analyzed the post-operative outcomes of obese vs non-obese patients in the subgroup undergoing laparoscopic CRC surgery.

Research results
This research has demonstrated that although obese patients were more likely to experience conversion to an open procedure \( (P = 0.002) \), they did not experience more post-operative complications \( (P = 0.06) \) or high-grade complications \( (P = 0.11) \). There were also no differences in in-hospital mortality \( (P = 0.06) \) or length of stay \( (P = 0.42) \). In the laparoscopic subgroup however, patients were more likely to experience a post-operative complication \( (P = 0.05) \), but did not experience more high-grade complications \( (P = 0.07) \).

Research conclusions
Our study has determined that obesity is no barrier to adequate post-operative outcomes following CRC surgery, with obese patients having equivalent post-operative outcomes compared to their non-obese counterparts. Caution is advised however, when attempting a laparoscopic approach in obese patients.

Research perspectives
Although BMI is a well-recognized and accepted surrogate marker of obesity, further studies in this area should analyze post-operative outcomes using other markers of visceral obesity. In addition, the effect of nutritional status and body composition on post-operative outcomes can be explored.

FOOTNOTES

Author contributions: Mao D designed the study, performed the research, and wrote the manuscript; Flynn DE designed the study methodology and helped perform the research; Yerkovich S helped with data collection, statistical analysis, and manuscript review; Tran K and Gurunathan U helped with data collection, clinical advice, data analysis, and manuscript review; Chandrasegaram MD helped with design methodology and conceptualization, study supervision, manuscript editing and finalization.

Institutional review board statement: Ethics approval for this database was granted by the Prince Charles Hospital Human Research Ethics Committee (Approval No. HREC/17/QPCH/295).
Informed consent statement: I certify that patients were not required to give informed consent to the study because the analysis used anonymous clinical data that was obtained after each patient agreed to treatment by written consent.

Conflict-of-interest statement: All the authors report no relevant conflicts of interest for this article.

Data sharing statement: No additional data are available.

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S-Editor: Wang JJ
L-Editor: Filipodia
P-Editor: Wang JJ

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