Surg Endosc (2016) 30:5572–5582
DOI 10.1007/s00464-016-4930-x

Decreased risk of surgery for small bowel obstruction after laparoscopic colon cancer surgery compared with open surgery: a nationwide cohort study

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Received: 4 February 2016 / Accepted: 8 April 2016 / Published online: 29 April 2016

Abstract
Background The impact of surgical approach on the incidence of small bowel obstruction (SBO) is unclear. The aim of the current study was to analyze the long-term risk of surgery for SBO after open and laparoscopic surgery and to assess how subsequent SBO surgery impacts on mortality after colonic cancer resection.
Methods This was a nationwide cohort study of patients undergoing elective colonic cancer resection with primary anastomosis in Denmark between 2001 and 2008. All included patients were operated with curative intent. Patients were identified in the Danish Colorectal Cancer Group database and followed through May 2014 in the Danish National Patient Register. The primary endpoint was surgery for SBO. Secondarily, mortality among patients who subsequently underwent SBO surgery and those who did not was compared.
Results Among the 8583 included patients, 251 (2.9 %) underwent surgery for SBO during follow-up (median 8.8 years). The 3-year cumulative incidence of SBO surgery was 1.5 %; 1.2 % after laparoscopic and 1.6 % after open surgery. Laparoscopic surgery was associated with a decreased risk of SBO (hazard ratio [HR] 0.61 (CI 0.37 to 0.99, $P = 0.048$) compared with open surgery. The HR for mortality after colonic resection was 2.54 (CI 1.91 to 3.38, $P < 0.001$) for patients who underwent subsequent SBO surgery as compared to those who did not.
Conclusions Laparoscopic surgery for colonic cancer was associated with a decreased risk of subsequent SBO surgery compared with open surgery. Further, subsequent SBO surgery was associated with increased mortality after colonic cancer resection.

Keywords Adhesions · Complications · Mortality · Minimally invasive

Laparoscopic surgery for colorectal cancer is increasingly being implemented worldwide. In Denmark, the rate of surgery performed laparoscopically for colorectal cancer has risen from 18 % in 2006 to 68 % in 2014 [1], and from 35 % in 2006 to 51 % in 2010 at Comprehensive Cancer Centres in North America [2]. Compared with open surgery, laparoscopic colonic surgery leads to less intraoperative blood loss, fewer postoperative complications, and shorter postoperative admissions [3] while achieving equal oncological results [4]. A shift from open to laparoscopic surgery could potentially reduce the risk of long-term small bowel obstruction (SBO) because of fewer adhesions [5]. Several studies have compared the incidence of SBO after open and laparoscopic surgery, but with conflicting results. The reported incidences of SBO are 3.1–13.0 % after open and 2.5–9.0 % after laparoscopic colonic surgery [6–10]. SBO is a serious long-term complication to surgery and is associated with a high morbidity and is costly to society [11, 12].

Electronic supplementary material The online version of this article (doi:10.1007/s00464-016-4930-x) contains supplementary material, which is available to authorized users.

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In the current study, the long-term risk of SBO requiring surgery in patients subjected to laparoscopic or open elective colonic cancer surgery was investigated in a nationwide setting. Secondly, the impact of subsequent SBO surgery on mortality after colonic cancer resection was assessed together with the impact of the surgical approach for colon cancer on mortality after SBO surgery.

Materials and methods

This was a nationwide cohort study on prospectively registered data from the database of the Danish Colorectal Cancer Group (DCCG). The DCCG database holds information on at least 95 % of all patients diagnosed with colorectal cancer in Denmark [13]. The study cohort consisted of patients who underwent elective curative colonic resection for adenocarcinoma with primary anastomosis, without a protective stoma, between May 1, 2001, and December 31, 2008. These inclusion criteria were used to ensure that the setting and the clinical condition was largely comparable among patients. This cohort has previously been assessed and validated [14].

The exposure of interest was surgical approach (laparoscopic or open) for colonic surgery. During the study period, laparoscopic surgery was being implemented without overall national control. Thus, the choice of surgical approach for colonic resection was according to both the department and the surgeon planning and performing the procedure. Procedures converted from laparoscopic to open surgery were not recorded separately in the DCCG database, but recorded as open procedures. Patients were included in the study at time of colon cancer resection defined as the index operation.

The primary endpoint was SBO defined as any operation for SBO from 30 days after the index operation. SBO was identified using procedure codes (Appendix A of Electronic Supplementary Material) registered in the Danish National Patient Registry (DNPR). This registry holds information on all diagnosis (International classification of diseases, 10th edition) and procedure codes (Nordic Medico-Statistical Committee [NOMESCO]) related to all Danish patients admitted to a hospital since 1977 [15].

The secondary endpoint was mortality, which was assessed with two different aims: (1) The impact of SBO surgery on mortality after the index operation and (2) the impact of surgical approach at the index operation on mortality after SBO surgery.

Covariates were collected from the DCCG database and included age, gender, body mass index (BMI), smoking status, Union for International Cancer Control (UICC) tumor stage, year of surgery, type of colonic resection, surgeons' level of specialty defined as gastrointestinal specialists compared with non-gastrointestinal specialists, intraoperative blood loss, and peri-operative blood transfusion. Because data completeness of patient-reported data was <50 % in the DCCG database, information on height and weight was supplemented using data from the Danish Anaesthesiology Database, which holds information on 75 % of all patients undergoing general anesthesia [16]. Comorbidity was assessed using the Charlson comorbidity index (CCI) [17] and was categorized as none (score 0), moderate (score 1), severe (score 2), and very severe (score ≥3). Information on postoperative wound infection, fascial dehiscence, and additional abdominal surgical procedures subsequent to the index operation was obtained using diagnosis and procedure codes registered in the DNPR (Appendix A of Electronic Supplementary Material). Information on adjuvant chemotherapy was also collected from the DNPR (Appendix A of Electronic Supplementary Material) and defined as procedure codes for initiation of treatment within 120 days from the index operation.

This study was written according to the STROBE guidelines [18]. The study was approved by the Danish National Data Protection Agency (j.no 2012-58-0004, local ref. BBH-2014-046).

Statistics

For patients undergoing laparoscopic and open colonic surgery, covariates were presented as absolute numbers with percentage, while blood loss was presented as median with interquartile range. In the primary analysis, patients were followed from time of laparoscopic or open colon cancer resection (index operation) until time of SBO, other abdominal surgeries, death, or end of follow-up, whichever came first.

The 3-year cumulative incidence of SBO was analyzed with death and subsequent surgery as competing risks. SBO risk among colon cancer patients undergoing laparoscopic and open surgery was compared using two different multivariable models. In the first model, a Cox regression analysis validated for proportional hazards using cumulative Martingale residuals was used [19]. In the second model, death and additional abdominal surgery were treated as competing risks using a logistic link analysis [20, 21]. For both models, surgery for SBO was the endpoint and both models included all available covariates. In order to assess whether the complete case analyses was biased by missing data, inverse probability weighting was used for both models. Briefly, this is a statistical method for handling missing values, as an alternative to multiple imputation [22]. Due to nonlinearity, age and BMI were categorized into four (<60 years, >60–70 years, >70–80 years and >80 years) and three (<25 kg/m^2, 25–30 kg/m^2 and >30 kg/m^2) groups, respectively.

In the secondary analyses, the impact of surgery for SBO on the overall long-term mortality after colonic cancer resection was evaluated using multivariable Cox regression analysis. Patients were followed from date of the index operation and surgery for SBO, and other abdominal procedures were included as time-varying covariates along with the previously described covariates. In another analysis, only the subset of patients undergoing SBO surgery was included. This subset of patients was followed from time of SBO surgery until death or end of follow-up, and mortality was compared among those with previous laparoscopic and open surgery using univariable Cox regression analysis. All analyses were two-sided, and a P value <0.05 was regarded significant. Length of follow-up was calculated using the reverse Kaplan–Meier method [23] and presented as median (interquartile range). Statistical analyses were undertaken using *R* 3.2 (Foundation for Statistical Computing, Vienna, Austria).

Results

Characteristics

The study cohort comprised 8601 patients, of which 18 were lost to follow-up leaving 8583 patients for statistical analysis (Fig. 1). Of these, 1604 (18.7 %) underwent laparoscopic colonic resection (Table 1). As compared with patients undergoing open surgery, patients undergoing laparoscopic surgery were younger ($P < 0.001$), were more often operated by a gastrointestinal specialist (98.7 vs 67.7 %, $P < 0.001$), and more often received postoperative chemotherapy (21.9 vs 17.7 %, $P < 0.001$). Fascial dehiscence (2.7 vs 0.6 %, $P < 0.001$), intra-operative blood loss (median 200 vs 50 ml, $P < 0.001$), and blood transfusion (26.0 vs 13.6 %, $P < 0.001$) were more common in open than laparoscopic surgeries. The median follow-up was 9.6 years (IQR 7.7–11.2) for patients undergoing open surgery and 7.0 years (IQR 6.1–8.0) for patients undergoing laparoscopic surgery.

SBO risk

A total of 251 (2.9 %) patients underwent surgery for SBO. The overall three-year cumulative incidence of SBO surgery was 1.5 % (95 % confidence interval [CI] 1.3–1.8). Among patients undergoing laparoscopic surgery, the 3-year cumulative incidence was 1.2 % (CI 0.6–1.6), whereas it was 1.6 % (CI 1.3–1.9) after open surgery (Fig. 2). The median time to SBO surgery was 19.1 months (IQR 2.8–47.9). Surgery for SBO was more common in patients who perioperatively received blood transfusion (3.6 vs 2.7 %, $P = 0.048$). Patients undergoing SBO surgery had increased mean blood loss during the index operation (380 vs 310 ml, $P = 0.014$) and a lower BMI (24.5 vs 25.4 kg/m^2, $P = 0.005$) as compared to patients not undergoing SBO surgery (Table 2).

Multivariable cox regression analysis showed that laparoscopic surgery was associated with a decreased risk of SBO compared with open surgery (hazard ratio [HR] 0.61, CI 0.37–0.99, $P = 0.048$, Table 3). Additional factors associated with increased risk of SBO in the

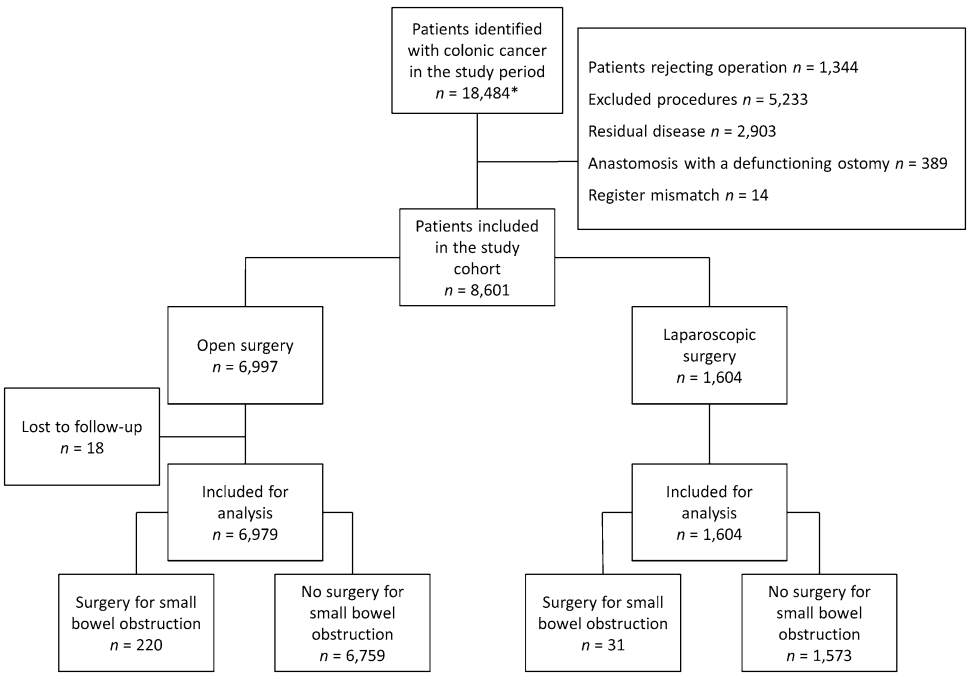

Fig. 1 Patient flowchart. *Modified from Krarup et al. [17]

Table 1 Patient characteristics according to surgical approach

Variable	Open colonic resection $n = 6979$ n (%)	Laparoscopic colonic resection $n = 1604$ n (%)	P
Age, years			<0.001
≤60	1149 (16.5)	311 (19.4)	
>60–70	1800 (25.8)	452 (28.2)	
>70–80	2514 (36.0)	563 (35.1)	
>80	1516 (21.7)	278 (17.3)	
Gender			0.207
Female	3627 (52.0)	805 (50.2)	
Male	3352 (48.0)	799 (49.8)	
Smoking status			0.048
Non-smoker	3360 (48.1)	769 (47.9)	
Active smoker	1661 (23.7)	435 (27.1)	
Missing data	1958 (28.1)	400 (24.9)	
Body mass index, kg/m^2			0.919
<25	2534 (36.3)	622 (38.8)	
25–30	1722 (24.7)	418 (26.1)	
>30	687 (9.8)	162 (10.1)	
Missing data	2036 (29.2)	402 (25.1)	
Comorbidity			0.499
None	5267 (75.5)	1215 (75.7)	
Moderate	878 (12.6)	193 (12.0)	
Severe	532 (7.6)	137 (8.5)	
Very severe	274 (3.9)	56 (3.5)	
Missing data	28 (0.4)	3 (0.2)	
UICC stage			<0.001
Stage I	992 (14.2)	341 (21.3)	
Stage II	3449 (49.4)	665 (41.5)	
Stage III	2235 (32.0)	555 (34.6)	
Missing data	303 (4.3)	43 (2.7)	
Procedure			<0.001
Right colectomy	3568 (51.1)	555 (34.6)	
Transverse colectomy	211 (3.0)	13 (0.8)	
Left colectomy	758 (10.9)	460 (10.0)	
Sigmoid colectomy	2442 (35.0)	876 (54.6)	
Year of surgery			<0.001
2001	654 (9.4)	19 (1.2)	
2002	939 (13.5)	27 (1.7)	
2003	1031 (14.8)	17 (1.1)	
2004	1079 (15.5)	58 (3.6)	
2005	956 (13.7)	195 (12.2)	
2006	857 (12.3)	356 (22.2)	
2007	815 (11.7)	405 (25.2)	
2008	648 (9.3)	527 (32.9)	
Surgeon's speciality			<0.001
Gastrointestinal specialist	4722 (67.7)	1583 (98.7)	
General surgeon	2255 (32.3)	21 (1.3)	
Missing data	2(0)	0 (0)	

Table 1 continued

Variable	Open colonic resection $n = 6979$ n (%)	Laparoscopic colonic resection $n = 1604$ n (%)	P
Blood loss (ml)			<0.001
Median (interquartile range)	200 (100–400)	50 (20–100)	
Missing (%)	348 (5.0)	4 (0.2)	
Blood transfusion			<0.001
No	5112 (73.2)	1381 (86.1)	
Yes	1797 (25.7)	218 (13.6)	
Missing data	70 (1.0)	5 (0.3)	
Wound infection			0.215
No	6849 (98.1)	1582 (98.6)	
Yes	130 (1.9)	22 (1.4)	
Fascial dehiscence			<0.001
No	6790 (97.3)	1595 (99.4)	
Yes	189 (2.7)	9 (0.6)	
Anastomotic leak			0.389
No	6552 (93.9)	1496 (93.3)	
Yes	427 (6.1)	108 (6.7)	
Adjuvant chemotherapy			<0.001
No	5743 (82.3)	1253 (78.1)	
Yes	1236 (17.7)	351 (21.9)	

Comorbidity according to Charlson comorbidity index scores: normal (0), moderate (1), severe (2), and very severe (≥3)

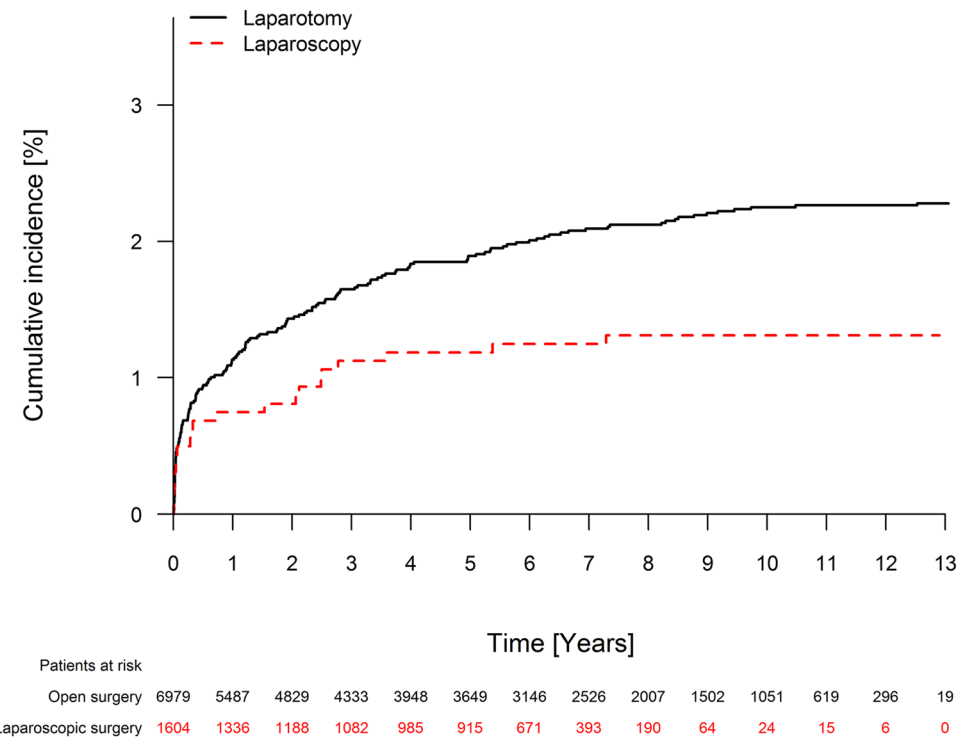

Fig. 2 Cumulative incidence of SBO after open and laparoscopic colonic resection for cancer. Additional abdominal surgery and death taken into account as competing risks

multivariable analysis were anastomotic leak (HR 1.78, CI 1.03–3.05, $P = 0.037$), perioperative blood transfusion (HR 2.20, CI 1.54–3.13, $P < 0.001$) and left (HR 1.83, CI 1.17–2.88, $P = 0.009$) and sigmoid colectomy (HR 1.54, CI 1.09–2.18, $P = 0.015$) compared with right colectomy. BMI of 25–30 kg/m^2 (HR 0.66, CI 0.47–0.93, $P = 0.017$)

Table 2 Univariable analysis according to subsequent surgery for small bowel obstruction

Variable	No surgery for small bowel obstruction $n = 8332$ n (%)	Surgery for small bowel obstruction $n = 251$ n (%)	HR	95 % CI	P
Surgical approach					0.015
Open	6759 (81.1)	220 (87.6)	1.00		
Laparoscopic	1573 (18.9)	31 (12.4)	0.63	0.43–0.91	
Age, years					0.850
≤60	1409 (16.9)	51 (20.3)	1.00		
>60–70	2184 (26.2)	68 (27.1)	0.92	0.64–1.33	0.660
>70–80	2984 (35.8)	93 (37.1)	1.04	0.74–1.46	0.834
>80	1755 (21.1)	39 (15.5)	0.91	0.60–1.38	0.652
Gender					0.363
Female	4292 (51.5)	140 (55.8)	1.00		
Male	4040 (48.5)	111 (44.2)	0.89	0.69–1.14	
Smoking status					0.539
Non-smoker	4006 (66.4)	123 (63.4)	1.00		
Active smoker	2025 (33.6)	71 (36.6)	1.10	0.82–1.47	
Missing data	2301	57			
BMI, kg/m^2					0.019
<25	3040 (51.0)	116 (61.1)	1.00		
25–30	2086 (35.0)	54 (28.4)	0.68	0.49–0.93	0.018
>30	829 (13.9)	20 (10.5)	0.62	0.39–1.00	0.049
Missing data	2377	61			
Comorbidity					0.414
None	6290 (75.8)	192 (76.5)	1.00		
Moderate	1039 (12.5)	32 (12.7)	1.19	0.82–1.73	0.368
Severe	647 (7.8)	22 (8.8)	1.34	0.86–2.09	0.193
Very severe	325 (3.9)	5 (2.0)	0.74	0.30–1.79	0.503
Missing data	31	0			
UICC stage					0.479
Stage I	1295 (16.2)	38 (16.4)	1.00		
Stage II	4002 (50.0)	112 (48.3)	1.01	0.70–1.45	0.971
Stage III	2708 (33.8)	82 (35.3)	1.19	0.81–1.75	0.382
Missing data	327	19			
Procedure					0.275
Right colectomy	4018 (48.2)	105 (41.8)	1.00		
Transverse colectomy	219 (2.6)	5 (2.0)	0.93	0.38–2.28	0.872
Left colectomy	884 (10.6)	34 (13.5)	1.45	0.98–2.13	0.062
Sigmoid colectomy	3211 (38.5)	107 (42.6)	1.16	0.89–1.52	0.276
Year of surgery					0.841
2001	652 (7.8)	21 (8.4)	1.00		
2002	930 (11.2)	36 (14.3)	1.22	0.71–2.12	0.467
2003	1013 (12.2)	35 (13.9)	1.14	0.66–1.97	0.650
2004	1107 (13.3)	30 (12.0)	0.87	0.49–1.53	0.623
2005	1113 (13.4)	38 (15.1)	1.16	0.67–1.99	0.599
2006	1180 (14.2)	33 (13.1)	0.99	0.56–1.72	0.958
2007	1191 (14.3)	29 (11.6)	0.89	0.50–1.59	0.703
2008	1146 (13.8)	29 (11.6)	1.00	0.56–1.77	0.994

Table 2 continued

Variable	No surgery for small bowel obstruction $n = 8332$ n (%)	Surgery for small bowel obstruction $n = 251$ n (%)	HR	95 % CI	P
Surgeon's speciality					0.305
Gastrointestinal specialist	6117 (73.4)	188 (74.9)	1.00		
General surgeon	2213 (26.6)	63 (25.1)	0.86	0.65–1.15	
Missing data	2	0			
Blood loss (per 100 ml)			1.04	1.02–1.06	<0.001
Median, ml (interquartile range)	200 (100–350)	250 (100–450)			
Missing data	342	10			
Blood transfusion					<0.001
No	6318 (76.5)	175 (70.9)	1.00		
Yes	1943 (23.5)	72 (29.1)	1.62	1.23–2.14	
Missing data	71	4			
Wound infection					0.091
No	8188 (98.3)	243 (96.8)	1.00		
Yes	144 (1.7)	8 (3.2)	1.84	0.91–3.72	
Fascial dehiscence					0.982
No	8139 (97.7)	246 (98.0)	1.00		
Yes	193 (2.3)	5 (2.0)	0.99	0.41–2.40	
Anastomotic leak					<0.001
No	7823 (93.9)	225 (89.6)	1.00		
Yes	509 (6.1)	26 (10.4)	2.33	1.55–3.50	
Adjuvant chemotherapy					0.254
No	6799 (81.6)	197 (78.5)	1.00		
Yes	1533 (18.4)	54 (21.5)	1.13	0.84–1.53	

Comorbidity according to Charlson comorbidity index scores: normal (0), moderate (1), severe (2), and very severe (≥3)

and >30 kg/m^2 (0.42, CI 0.23–0.75, $P = 0.003$) was associated with a decreased risk of SBO.

In the logistic link model where death without SBO and additional abdominal surgery before SBO were included as competing risks, similar findings were obtained (Table 3).

Mortality

During the follow-up period after the index operation, 4175 (48.6 %) patients died after a median of 36 months (IQR 14–67). In the multivariable analysis, subsequent surgery for SBO was associated with increased mortality (HR 2.26, CI 1.66–3.08, $P < 0.001$) as compared to patient not undergoing surgery after the initial colonic resection (Table 4).

Of the patients who underwent surgery for SBO, 55.1 % (130 of 251) died during follow-up. The median survival after surgery for SBO was 33 months (IQR 5–77). In this subset of patients, there was no statistically significant difference in mortality between patients who primarily underwent laparoscopic compared with open colonic surgery (crude HR 0.77, CI 0.35–1.40, $P = 0.389$).

Discussion

In the current study, a 39 % risk reduction in subsequent surgery for SBO comparing patients who primarily underwent laparoscopic resection to patients primarily undergoing open resection for colonic cancer was observed. Surgery for SBO subsequent to the initial colonic resection was associated with a significantly increased mortality compared with patients who did not undergo subsequent SBO surgery. Mortality after SBO surgery did not defer between patients who underwent open or laparoscopic surgery at the index operation.

Several other studies have assessed the risk of SBO surgery after open and laparoscopic surgery. Long-term follow-up of three multi-center randomized trials have yielded ambiguous results. Median 3.4 years after inclusion, open surgery was associated with an increased risk of SBO surgery in patients included in the LAFA study [24]. Contrary to this finding and with similar follow-up length, the CLASICC and COLOR trials reported no differences in risk of SBO surgery when comparing open and laparoscopic approach [6, 8]. The incidences of SBO surgery in

Table 3 Cox regression and competing risk model of factors associated with surgery for small bowel obstruction subsequent to colonic resection for cancer

Variable	Cox regression			Competing risk model		
	HR	95 % CI	*P*	OR	95 % CI	*P*
Surgical approach			0.048			0.050
Open	1.00			1.00		
Laparoscopic	0.61	0.37–0.99		0.60	0.36–0.99	
Age, years			0.598			0.422
≤60	1.00			1.00		
>60–70	1.01	0.63–1.61	0.971	0.99	0.62–1.60	0.973
>70–80	1.12	0.72–1.75	0.609	1.07	0.68–1.68	0.778
>80	0.83	0.48–1.43	0.499	0.72	0.40–1.31	0.285
Gender			0.298			0.318
Female	1.00			1.00		
Male	0.85	0.62–1.16		0.81	0.54–1.22	
Smoking status			0.827			0.966
Non-smoker	1.00			1.00		
Active smoker	0.96	0.70–1.33		1.01	0.67–1.52	
BMI, kg/m^2			0.020			0.018
<25	1.00			1.00		
25–30	0.66	0.47–0.93	0.017	0.65	0.42–1.00	0.049
>30	0.42	0.23–0.75	0.003	0.41	0.20–0.85	0.017
Comorbidity			0.796			0.852
None	1.00			1.00		
Moderate	1.16	0.73–1.85	0.528	1.07	0.59–1.94	0.821
Severe	1.39	0.82–2.35	0.221	1.33	0.67–2.63	0.420
Very severe	0.98	0.38–2.51	0.971	0.85	0.25–2.83	0.790
UICC stage			0.827			0.554
Stage I	1.00			1.00		
Stage II	0.92	0.61–1.40	0.704	0.90	0.53–1.51	0.682
Stage III	0.80	0.45–1.42	0.443	0.67	0.32–1.39	0.284
Procedure			0.018			0.023
Right colectomy	1.00			1.00		
Transverse colectomy	0.76	0.24–2.42	0.644	0.76	0.23–2.51	0.656
Left colectomy	1.83	1.17–2.88	0.009	1.79	1.13–2.83	0.013
Sigmoid colectomy	1.54	1.09–2.18	0.015	1.55	1.09–2.20	0.015
Year of surgery	1.02	0.93–1.11	0.734	1.01	0.92–1.10	0.881
Surgeon's speciality			0.489			0.484
Gastrointestinal specialist	1.00			1.00		
General surgeon	1.15	0.78–1.68		1.17	0.75–1.82	
Blood loss (per 100 ml)	1.00	0.96–1.03	0.785	0.99	0.96–1.02	0.532
Blood transfusion			<0.001			0.002
No	1.00			1.00		
Yes	2.20	1.54–3.13		2.05	1.29–3.25	
Wound infection			0.583			0.687
No	1.00			1.00		
Yes	1.33	0.48–3.74		1.24	0.44–3.48	
Fascial dehiscence			0.859			0.930
No	1.00			1.00		
Yes	0.91	0.33–2.49		0.95	0.34–2.66	

Table 3 continued

Variable	Cox regression			Competing risk model		
	HR	95 % CI	*P*	OR	95 % CI	*P*
Anastomotic leak						0.255
No	1.00			1.00		
Yes	1.78	1.03–3.05	0.037	1.38	0.79–2.42	
Adjuvant chemotherapy						0.628
No	1.00			1.00		
Yes	1.11	0.62–2.00	0.724	1.21	0.56–2.58	

Adjusted for missing data by inverse probability weighting

Comorbidity according to Charlson comorbidity index scores: normal (0), moderate (1), severe (2), and very severe (≥3)

these randomized trials were comparable to what was found in the current study, if no competing risks were taken into account (data not shown). The incidence of SBO after laparoscopic or open surgery was also examined in two recent population-based registry studies [7, 25], including patients subjected to colorectal resection. Both studies reported that laparoscopic approach decreased the risk for SBO surgery compared with open surgery. The inclusion of rectal resections may explain the higher incidence compared with the current study, since rectal surgery in general leads to higher incidences of SBO [26]. Although the difference in cumulative incidence of SBO surgery after laparoscopic compared to open surgery in the current study may seem small, adjustment for covariates revealed a 39 % decreased risk after laparoscopic surgery. Thus, the clinical impact of minimally invasive surgery on subsequent risk of SBO surgery is substantial.

Additional covariates were associated with SBO in the present study and could be of particular interest for future research on SBO. In accordance with the present findings, it has previously been reported that intraoperative blood loss, perioperative blood transfusion, and female gender was associated with an increased risk of subsequent SBO [7, 27]. Besides these results, the knowledge about risk factors for SBO is limited. Surprisingly, BMI >30 kg/m^2 was associated with a decreased risk of SBO compared with patients with a normal BMI. Since the prevalence of visceral obesity is >90 % in subjects with BMI >30 kg/m^2 [28], this could lead to the hypothesis that increasing amounts of intraperitoneal fat prevents either the formation of adhesions or the symptoms of these. Conversely, anastomotic leak was associated with an increased risk of SBO. The association between anastomotic leakage and SBO is in line with several experimental studies that point toward peritoneal inflammation as a key element in the formation of adhesions [29].

Among patients undergoing colon cancer resection, subsequent SBO surgery was associated with increased mortality compared to patients who did not undergo additional abdominal surgery. Postoperative mortality after SBO surgery has previously been reported to be 10 % [12]. To the knowledge of the authors, this is the first study to assess the impact of SBO surgery on long-term mortality and these findings highlight the importance of preventing the development of subsequent SBO.

No information on the underlying cause for SBO was available; however, intraperitoneal adhesions are in general the main cause of SBO [30], observed in 63–93 % of patients undergoing abdominal surgery [31, 32] and develop more often after open than after laparoscopic colorectal surgery [33]. Thus it is assumed that adhesions were the main cause of SBO in the present cohort. Conservatively managed SBO may be more common after laparoscopic compared with open colonic resection, due to less severe adhesions [5]. However, diagnosis of SBO without subsequent SBO surgery may be associated with a risk of misclassification bias and to minimize this risk, only surgically managed SBO was included in the current study. Other causes for SBO include obstructed hernias, recurrent or metachronic malignancy, and gall stone ileus [34], all of which are considered rare causes of SBO compared to adhesions [35]. To further examine this, review of patient charts and operative reports will be necessary.

Methodological considerations

Several factors may limit the validity of the conclusions of this study. Most notably, abdominal procedures prior to the index operation were not accounted for. This could potentially induce bias since patients who previously underwent surgery may be more prone to undergo open surgery, due to adhesions complicating the index operation. Furthermore, no information on converted procedures was available. This issue could represent another bias as existing adhesions are a cause for conversion of a laparoscopic procedure [36]. Only SBO episodes requiring surgery were evaluated. Laparoscopic surgery may lead to fewer and less symptomatic adhesions compared with open

Table 4 Cox regression of factors associated with mortality after colonic resection for cancer

Variable	HR	95 % CI	*P*
Additional abdominal surgery			<0.001
None	1.00		
Surgery for SBO	2.26	1.66–3.08	<0.001
Other abdominal surgery	2.07	1.84–2.33	<0.001
Surgical approach at index operation			0.593
Open	1.00		
Laparoscopic	0.97	0.85–1.10	
Age at index surgery, years			<0.001
≤60	1.00		
>60–70	1.64	1.37–1.96	<0.001
>70–80	2.84	2.39–3.37	<0.001
>80	5.67	4.72–6.81	<0.001
Gender			<0.001
Female	1.00		
Male	1.25	1.14–1.37	
Smoking status			0.002
Non-smoker	1.00		
Active smoker	0.86	0.78–0.94	
BMI, kg/m^2			0.394
<25	1.00		
25–30	0.94	0.85–1.04	0.212
>30	0.94	0.82–1.08	0.362
Comorbidity			<0.001
None	1.00		
Moderate	1.42	1.24–1.62	<0.001
Severe	1.52	1.30–1.77	<0.001
Very severe	2.52	2.01–3.15	<0.001
UICC stage			<0.001
Stage I	1.00		
Stage II	1.37	1.20–1.57	<0.001
Stage III	2.30	1.95–2.72	<0.001
Procedure			0.308
Right colectomy	1.00		
Transverse colectomy	1.03	0.75–1.43	0.844
Left colectomy	0.99	0.84–1.15	0.862
Sigmoid colectomy	0.91	0.82–1.01	0.072
Year of surgery	0.93	0.90–0.95	<0.001
Surgeon's speciality			0.781
Gastrointestinal specialist	1.00		
General surgeon	0.98	0.87–1.11	
Blood loss (per 100 ml)	1.02	1.01–1.13	0.004
Blood transfusion			0.169
No	1.00		
Yes	1.08	0.97–1.21	
Wound infection			0.546
No	1.00		
Yes	0.91	0.67–1.23	
Fascial dehiscence			0.447
No	1.00		
Yes	1.13	0.82–1.56	
Anastomotic leak			0.128
No	1.00		
Yes	1.21	0.95–1.53	
Adjuvant chemotherapy			0.208
No	1.00		
Yes	0.90	0.77–1.06	

Adjusted for missing data by inverse probability weighting

Comorbidity according to Charlson comorbidity index scores: normal (0), moderate (1), severe (2), and very severe (≥3). *SBO* small bowel obstruction

surgery, and thus it cannot be ruled out that non-operative treatment of SBO was more common after laparoscopic colonic resection in the current study. No information whether conservative treatment of SBO may be skewed according to previous laparoscopic or open surgery was available and lastly, the pathological mechanism for SBO was not examined in this study.

In conclusion, laparoscopic surgery for colonic cancer was associated with a decreased risk of subsequent SBO surgery compared with open surgery. Further, subsequent SBO surgery was associated with increased mortality after colonic cancer resection, suggesting that the laparoscopic approach has long-term advantages compared with open surgery.

Compliance with ethical standards

Disclosures Drs. Kristian K. Jensen, Peter Andersen, Rune Erichsen, Thomas Scheike, Lene H. Iversen and Peter-Martin Krarup have no conflicts of interest or financial ties to disclose.

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