ORIGINAL ARTICLE

Pulmonary Function Following Laparoscopic or Conventional Colorectal Resection

A Randomized Controlled Evaluation

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Background: Laparotomy causes a significant reduction of pulmonary function, and atelectasis and pneumonia occur after elective conventional colorectal resections.

Objective: To evaluate the hypothesis that pulmonary function is less restricted after laparoscopic than after conventional colorectal resection.

Design: A randomized clinical trial.

Setting: The surgical department of an academic medical center.

Patients: Sixty patients underwent laparoscopic (n = 30) or conventional (n = 30) resection of colorectal tumors. The 2 groups did not differ significantly in age, sex, localization or stage of tumor, or preoperative pulmonary function.

Main Outcome Measures: Forced vital capacity, forced expiratory volume in 1 second, peak expiratory flow, midexpiratory phase of forced expiratory flow, and oxygen saturation of arterial blood.

Results: The forced vital capacity (mean ± SD values: conventional resection group, 1.73 ± 0.60 L; laparoscopic surgery group, 2.59 ± 1.11 L; $P<.01$) and the forced expiratory volume in 1 second (conventional resection group, 1.19 ± 0.51 L/s; laparoscopic surgery group, 1.80 ± 0.80 L/s; $P<.01$) were more profoundly suppressed in the patients having conventional resection than in those having laparoscopic surgery. Similar results were found for the peak expiratory flow (conventional resection group, 2.51 ± 1.37 L/s; laparoscopic resection group, 3.60 ± 2.22 L/s; $P<.05$) and the midexpiratory phase of forced expiratory flow (conventional resection group, 1.87 ± 1.12 L/s; laparoscopic surgery group, 2.67 ± 1.76 L/s; $P<.05$). The oxygen saturation of arterial blood, measured while the patients were breathing room air, was lower after conventional than after laparoscopic resections ($P<.01$). The recovery of the forced vital capacity and forced expiratory volume in 1 second to 80% of the preoperative value took longer in patients having conventional resection than in those having laparoscopic resection ($P<.01$). Pneumonia developed in 2 patients having conventional resection, but no pulmonary infection occurred in the laparoscopic resection group ($P>.05$).

Conclusions: Pulmonary function is better preserved after laparoscopic than after conventional colorectal resection. Pulmonary complications may be reduced after laparoscopic resections because of the better postoperative pulmonary function.

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THE SUPPRESSION of pulmonary function is a well-known sequela of abdominal surgery and was first described in 1933 by Beecher.[1] Following upper abdominal incisions, forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1) are reduced by almost 60%[2-4] because of a reflectory dysfunction of the diaphragm. Because the functional residual capacity is decreased postoperatively, small airways collapse[5] and atelectasis occurs in most patients.[6] Regardless of the anesthetic technique, pulmonary function does not recover to preoperative values within the first postoperative week after conventional abdominal surgery, and intensive physiotherapy does not prevent pulmonary dysfunction.[1,7-10] Pneumonia is clinically apparent in more than 5% of all patients undergoing elective conventional colorectal resection and constitutes the most common general postoperative complication after conventional colorectal resection.[11-13]

See Invited Critique at end of article

Pulmonary function is better after simple laparoscopic procedures than after conventional surgery. Arterial oxygen saturation (SaO_2) is less impaired and at-

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PATIENTS AND METHODS

HYPOTHESIS, END POINTS, AND SAMPLE SIZE CALCULATION

We hypothesized that pulmonary function is less suppressed and recovers faster following laparoscopic than conventional colorectal resections. To test this hypothesis, we recorded postoperative changes in FVC, FEV_1, peak expiratory flow (PEF), the midexpiratory phase of forced expiratory flow ($FEF_{25\%-75\%}$), the relation of the FEV_1 to the FVC (FEV_1/FVC ratio), and SaO_2. The sample size needed to test the hypothesis was calculated according to the methods described by Altman.[19] The FVC and FEV_1 were chosen as major criteria for calculating the sample size. It was assumed that FVC and FEV_1 values decrease by 50% ± 20% (±SD) following conventional colorectal resections.[6] A difference of 15% in the postoperative FVC and FEV_1 values between the laparoscopic and conventional resection groups can be detected by a 2-tailed test with an α level of .05, a β level of .20 (power, 80%), and 30 patients in each group.

STUDY POPULATION

All patients with the diagnosis of a colorectal tumor who were scheduled for elective ascending colectomy, sigmoidectomy, proctosigmoidectomy, or abdominoperineal resection were included in the study. Patients who were scheduled for a sphincter-preserving anterior resection with total mesorectal excision of carcinoma of the middle or lower rectum (<12 cm from the anal verge) were excluded. Further exclusion criteria were intestinal obstruction, intraabdominal abscess or sepsis, infiltration of tumor into adjacent organs or a tumor of more than 8 cm in diameter on computed tomographic scan, severe obesity (body mass index [or Quetelet index], calculated as weight in kilograms-divided by the square of the height in meters, >32), operative risk greater than the American Society of Anesthesiologists' class III, and uncorrectable coagulopathy or thrombocytopenia.

STUDY DESIGN

The study was approved by the local ethics committee. Concomitant cardiopulmonary diseases of all patients were recorded, and medical treatment was optimized before surgery. An informed consent was obtained from every patient. Mechanical bowel preparation and the perioperative administration of antibiotics were the same in the 2 groups. Anesthesia with endotracheal intubation was performed in a standardized manner by the same anesthesiological team using sufentanil, propofol, and atracurium besylate. Intraoperative sufentanil doses in micrograms per kilogram of body weight per minute were comparable in both groups.

OPERATIVE TECHNIQUE AND INTRAOPERATIVE RANDOMIZATION

All patients underwent a diagnostic laparoscopy. When the surgeon decided during the diagnostic laparoscopy that laparoscopic resection of the tumor was feasible, intraoperative randomization was accomplished, and a laparoscopic or conventional resection was carried out. If the surgeon decided that laparoscopic resection could not be performed, the patient was excluded from further evaluation and underwent a conventional resection. All laparoscopic procedures were performed by an experienced laparoscopic team using a standardized 5-trocar technique (infraumbilical and middle and lower abdomen bilaterally) that has been described in detail elsewhere.[20] During proctosigmoidectomy and abdominoperineal resection, high ligation of the inferior mesenteric artery was accomplished with a linear endoscopic stapling device (EndoGIA 30; Autosuture Germany,

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electasis occurs less often after laparoscopic than after conventional cholecystectomy.[3,14-16] Although the laparoscopic approach to colorectal diseases has been reported by some authors[11,17] to be beneficial, it is still questionable whether laparoscopic colorectal resection actually results in better postoperative pulmonary function.[18] A randomized study was conducted to determine whether postoperative pulmonary function is better following laparoscopic than conventional colorectal resections.

RESULTS

From April 19, 1995, to October 24, 1996, 60 patients were randomly assigned to laparoscopic (n = 30) or conventional (n = 30) resection of colorectal tumors. An 86-year-old patient in the laparoscopic resection group was switched to a laparoscopic-assisted sigmoidectomy because of tumor infiltration of the left ovary and was included in the laparoscopic group for an intent-to-treat analysis. After conventional sigmoidectomy, 1 patient required a second laparotomy because of hemorrhage from the greater omentum at the splenic flexure. The patient received mechanical ventilation for 24 hours after primary surgery.

Patient demographics are shown in **Table 1**. There were no significant differences in these characteristics between the groups. Preoperatively, the FVC and FEV_1 values, the FEV_1/FVC ratio, and the PEF, $FEF_{25\%-75\%}$, and SaO_2 values were comparable between the groups (**Table 2**). None of the patients had pulmonary function values below 70% of expected for their age. Preoperative results of the spirometric tests were correlated to the results of body plethysmography (FVC, $r = 0.93$, $P<.001$; and FEV_1, $r = 0.89$, $P<.001$).

The operating time was 219 ± 64 minutes for the laparoscopic resection group and 146 ± 41 minutes for the conventional resection group ($P<.01$). Postoperative morbidity and the number of deaths are shown in **Table 3**. The mean length of postoperative hospital stays was 10.1 ± 3.0 days in the laparoscopic resection group and 11.6 ± 2.0 days in the conventional resection group ($P<.05$). One patient with sigmoid carcinoma and diffuse liver metastases was discharged 9 days after conventional surgery but died 14 days later of hepatic failure.

The postoperative suppression of pulmonary function (FVC, FEV_1, PEF, and $FEF_{25\%-75\%}$) was more severe after conventional than after laparoscopic resection

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Toenisvorst, Germany). During ascending colectomies, the ileocolic and right colic arteries were dissected with a stapler close to their origin from the superior mesenteric artery. In all resections with curative intent, a systematic regional lymphadenectomy was performed. After resection, the specimen was retrieved through a minilaparotomy of 3 to 4 cm in the left lower abdomen (proctosigmoidectomy) or the infraumbilical region (ascending colectomy). During ascending colectomy, a functional end-to-end ileotransversostomy was performed extracorporeally with a linear stapling device (GIA80; Autosuture Germany). For a proctosigmoidectomy, the anvil of a circular stapling device (Premium Plus CEEA; Autosuture Germany) was inserted into the descending colon extracorporeally. Then the minilaparotomy was closed, the pneumoperitoneum was reestablished, and the anastomosis between the descending colon and rectum was performed using the "double-stapling" technique. The anatomical extent of resection and the anastomotic technique were similar in the conventional surgery, but the resection was accomplished through a wide midline laparotomy.

POSTOPERATIVE ANALGESIA, PULMONARY FUNCTION, AND SaO_2

All patients received patient-controlled analgesia with morphine sulfate until the morning of the fourth postoperative day and, from then on, tramadol hydrochloride orally until discharge. Pain was assessed using a visual analog scale during rest and during coughing. The patient-controlled anesthesia bolus was increased when the visual analog scale score at rest was higher than 50. All patients received supplemental oxygen (2-6 L/min) until the morning of the first postoperative day. Patients were discharged from the surgical intensive care unit to the regular nursing floor on the first postoperative day. Bedside spirometry (Renaissance Spirometer; Firma Puritan Bennett Hoyer, Gräfeling, Germany) was carried out with the patients lying in bed and the upper body elevated by 45°. Each test was repeated 3 times, and the best of the 3 results for FVC, FEV_1, PEF, and $FEF_{25\%-75\%}$ were chosen for further analysis.[21] The FEV_1/FVC ratio (in percentage) was calculated from these values. Spirometry was performed preoperatively, 3 times per day from the first to the third day, twice a day from the fourth to the sixth day, and once a day from the seventh day until discharge. At the same time, SaO_2 was measured by pulse oximetry (Oxyshuttle+2; Critikon, Norderstedt, Germany) while the patients were breathing room air. Body plethysmography was performed preoperatively and on the fifth postoperative day in the Department of Pulmonology to validate the results of the spirometric tests.

All patients received patient-controlled analgesia with morphine sulfate immediately after surgery until the eighth postoperative day. The doses were adjusted according to the patients' subjective pain perception, which was assessed every 8 hours by visual analog scale. All intraoperative and postoperative complications and mortality were recorded until 30 days after surgery. Pneumonia was diagnosed when patients had a temperature higher than 38°C, a productive cough, and radiological evidence of infection. To complete the measurements of the first postoperative week, patients were not discharged before the seventh postoperative day.

DATA COLLECTION AND STATISTICAL ANALYSIS

Normally distributed continuous data are given as mean ± SD and were compared between the groups using the Student *t* test. If appropriate, the Wilcoxon rank sum test was performed. Categorical data were compared using the Fisher exact test. Correlations between continuous values were calculated using the Spearman rank test. A *P* value of .05 was considered significant. Statistical analysis of all data was performed using commercial software (SAS for Windows; SAS Institute Inc, Cary, NC).

(**Table 4**). The results of spirometric tests and body plethysmography in the postoperative period were also highly correlated (FVC, $r = 0.96$, $P < .001$; and FEV_1, $r = 0.94$, $P < .001$). Improvement of pulmonary function had the same slope in both groups (**Figure 1** through **Figure 3**). Recovery to 80% of the preoperative FVC value was achieved after 2.9 ± 2.0 days in the laparoscopic resection group and after 5.2 ± 2.6 days in the conventional resection group ($P < .01$) (Figure 1). Recovery of 80% of the preoperative FEV_1 value took 3.0 ± 2.2 days in the laparoscopic resection group and 5.7 ± 3.2 days in the conventional resection group ($P < .01$) (Figure 2). The postoperative values of the PEF reached 80% of the preoperative level within 3.9 ± 3.3 days in the laparoscopic resection group and 5.7 ± 3.7 days in the conventional resection group (Figure 3). The $FEF_{25\%-75\%}$ reached 80% of the preoperative value within 3.2 ± 2.9 days after laparoscopic resection and 4.9 ± 3.2 days after conventional resection ($P < .05$). There were no differences in the FEV_1/FVC ratio between the groups.

Preoperative SaO_2 values were comparable between the groups (Table 2). From the morning of the first postoperative day, the SaO_2 value was lower after conventional resection than after laparoscopic surgery (**Figure 4**). Although the SaO_2 value remained almost unchanged in the laparoscopic resection group, it continuously decreased in the conventional resection group until 2 PM of the second day after surgery (Figure 4). The SaO_2 value at least once was lower than 90% in 22 patients (73%) having conventional resection but in only 14 patients (47%) having laparoscopic resection ($P = .06$).

COMMENT

Postoperative pneumonia occurs in more than 5% of all patients after elective conventional colorectal resection.[11-13] The reason for this incidence of postoperative pneumonia is a prolonged impairment of pulmonary function induced by laparotomy.[3-7,23] After a midline laparotomy, pulmonary function is depressed to about 50% of the preoperative value,[3,5,6,23] and complete recovery of pulmonary function after abdominal surgery usually takes 7 or more days.[3,4] Pulmonary function is more depressed after incisions in the upper abdomen than after lower abdominal laparotomy.[3,5,7] Colorectal carcinoma, inflammatory bowel disease, or diverticular disease require the resection of larger bowel segments.[24] Mobili-

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Table 1. Characteristics of Patients Undergoing Laparoscopic or Conventional Resection of Colorectal Tumors*

Characteristic	Patient Group: Laparoscopic Resection (n = 30)	Patient Group: Conventional Resection (n = 30)	P†
Age, mean ± SD, y	63.3 ± 12.2	64.8 ± 14.7	.67
BMI, mean ± SD, kg/m^2	24.7 ± 2.9	24.7 ± 2.4	>.99
Sex			
Male	14 (47)	16 (53)	.80
Female	16 (53)	14 (47)	
Concomitant diseases‡			
Cardiac	6 (20)	10 (33)	.38
Arterial hypertension	7 (23)	4 (13)	.51
Diabetes mellitus	2 (7)	4 (13)	.67
Pulmonary	1 (3)	3 (10)	.61
Hepatic	0	1 (3)	>.99
None	20 (67)	13 (43)	.12
ASA class			
I	14 (47)	9 (30)	.29
II	14 (47)	19 (63)	
III	2 (7)	2 (7)	
Type of resection			
Ascending colectomy	4 (13)	3 (10)	.83
Proctosigmoidectomy	22 (73)	24 (80)	
Abdominoperineal resection	4 (13)	3 (10)	
Tumor stage§			
0 (adenoma)	1 (3)	3 (10)	.19
I	9 (30)	8 (27)	
II	12 (40)	5 (17)	
III	6 (20)	8 (27)	
IV	2 (7)	6 (20)	

*Values are number (percentage) unless otherwise indicated.
†For age and BMI, the Student t test was used; for all other variables, the Fisher exact test.
‡Some patients had more than 1 concomitant disease.
§From the Union Internationale Contre le Cancer.[22]

Table 2. Preoperative Values of Pulmonary Function Tests and Pulse Oximetry in Patients Undergoing Laparoscopic or Conventional Resection of Colorectal Tumors*

Test	Patient Group: Laparoscopic Resection (n = 30)	Patient Group: Conventional Resection (n = 30)	P†
FVC, L	3.62 ± 1.26	3.38 ± 1.07	.44
FEV_1, L/s	2.57 ± 0.90	2.36 ± 0.95	.39
FEV/FVC ratio, %	81.2 ± 4.6	78.9 ± 10.8	.30
PEF, L/min	5.83 ± 2.64	5.57 ± 2.89	.71
$FEF_{25\%-75\%}$, L/min	4.11 ± 2.19	4.07 ± 2.58	.94
Sao_2, %	95.76 ± 1.24	95.77 ± 1.52	.98

*Data are given as mean ± SD. FVC indicates forced vital capacity; FEV_1, forced expiratory volume in 1 second; PEF, peak expiratory flow; $FEF_{25\%-75\%}$, midexpiratory phase of forced expiratory flow; and Sao_2, arterial oxygen saturation.
†Student t test.

zation of the splenic or hepatic flexure is necessary in many cases, and exploration of the upper abdomen and the liver is mandatory in patients with malignant neoplasms. Therefore, the midline laparotomy is extended to the upper abdomen in most colorectal resections.

Table 3. Postoperative Morbidity and Death After Laparoscopic and Conventional Resection of Colorectal Tumors*

Variable	Patient Group: Laparoscopic Resection (n = 30)	Patient Group: Conventional Resection (n = 30)	P†
Major complications‡			
Hemorrhage on day of primary surgery	0	1	>.99
Intraperitoneal abscess§	0	1	>.99
Minor complications‖			
Pneumonia	0	2	.49
Perineal wound healing impairment	0	1	>.99
Symptomatic hyperglycemia	0	1	>.99
Central venous (CV) line infection	0	1	>.99
Brachial plexus lesion (CV line)	0	1	>.99
Urinary tract infection	2	0	.49
Surgical morbidity	0	3	.20
Total morbidity	2	8	.08
Death			
In hospital	0	0	>.99
<30 d	0	1	>.99

*Data are the number of patients.
†Fisher exact test.
‡Requiring a laparotomy.
§On 17th postoperative day.
‖Requiring medical treatment.

Table 4. Pulmonary Function at 2 PM on the First Day After Laparoscopic or Conventional Resection of Colorectal Tumors*

Test	Patient Group: Laparoscopic Resection (n = 30)	Patient Group: Conventional Resection (n = 30)	P†
FVC, L	2.59 ± 1.11	1.73 ± 0.60	<.01
FEV_1, L/s	1.80 ± 0.80	1.19 ± 0.51	<.01
PEF, L/s	3.60 ± 2.22	2.51 ± 1.37	<.05
FEV_1/FVC ratio, %	69.6 ± 11.0	67.7 ± 9.8	.51
$FEF_{25\%-75\%}$, L/s	2.67 ± 1.76	1.87 ± 1.12	<.05
Sao_2, %	93.8 ± 1.9	92.1 ± 3.3	<.05

*Data are given as mean ± SD of actual values and percentage of preoperative values. The abbreviations are the same as explained in the first footnote of Table 2.
†Student t test.

The main reason for the suppression of pulmonary function after laparotomy is a decreased or even a paradoxical upward movement of the diaphragm during inspiration.[25-27] Because of this diaphragmatic malfunction, a postoperative shift from abdominal (ie, diaphragmatic) to thoracic (ie, rib cage) breathing occurs, tidal volume is markedly decreased, and respiratory frequency is increased.[28] The small airways of the lung (<1.0 mm in diameter) are not supported by cartilage and are influenced by transmitted intrapleural pressures. Normally, pleural pressures are less than atmospheric pressure, producing a positive transpulmonary pressure that

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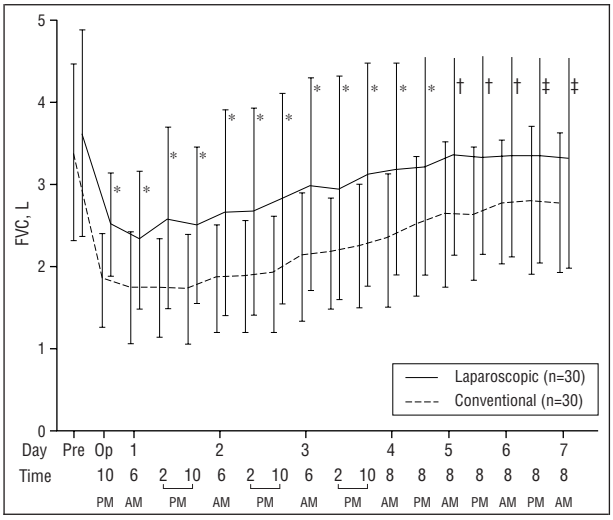

Figure 1. *Postoperative changes in forced vital capacity (FVC) following laparoscopic or conventional resection of colorectal tumors. Pre indicates preoperative measurement; Op, day of surgery; asterisk,* P = *.01; dagger,* P<*.05; and double dagger,* P = *.06.*

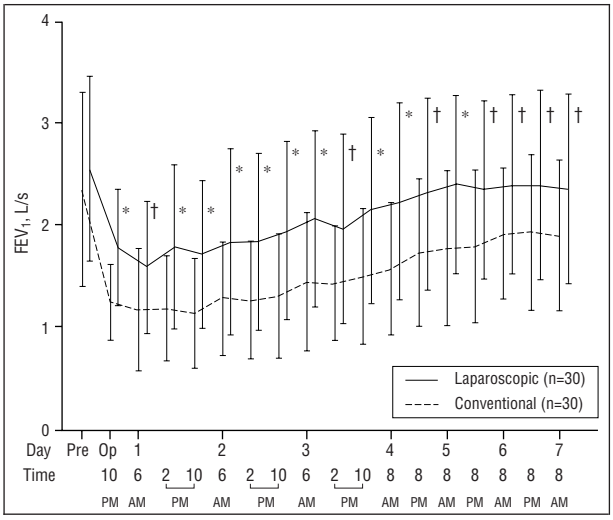

Figure 2. *Postoperative changes in forced expiratory volume in 1 second (FEV_1) following laparoscopic or conventional resection of colorectal tumors. Pre indicates preoperative measurement; Op, day of surgery; asterisk,* P<*.01; and dagger,* P<*.05.*

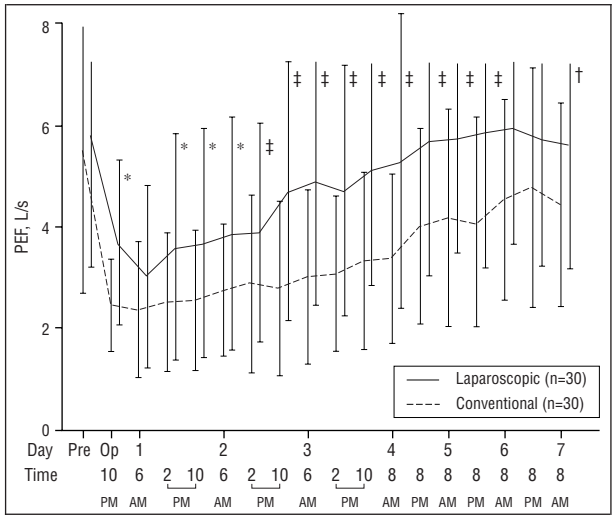

Figure 3. *Postoperative changes in peak expiratory flow (PEF) following laparoscopic or conventional resection of colorectal tumors. Pre indicates preoperative measurement; Op, day of surgery; asterisk,* P<*.05; dagger,* P = *.06; and double dagger,* P<*.01.*

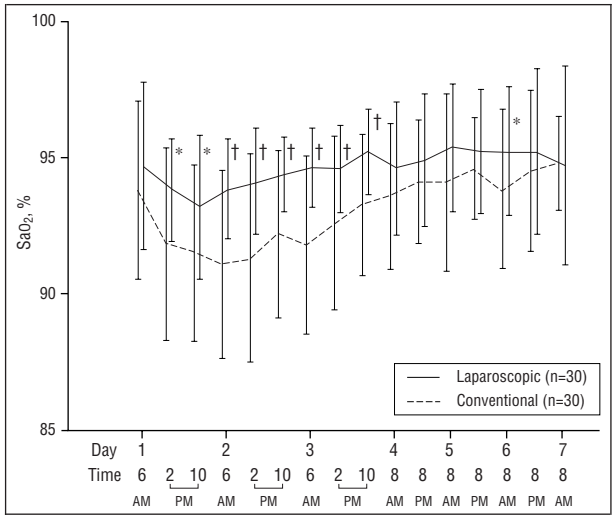

Figure 4. *Postoperative changes in oxygen saturation of the arterial blood (Sa_{O_2}), measured while patients are breathing room air, following laparoscopic or conventional resection of colorectal tumors. Asterisk indicates* P<*.05; dagger,* P<*.01.*

distends these small airways.[4] Because of the postoperative diaphragmatic malfunction, the intrapleural pressure rises and a negative transpulmonary pressure develops. This negative transpulmonary pressure causes the small airways to collapse.[4] Collapse or narrowing of small airways will result in a reduction of ventilation to affected lung regions and produce a low ventilation-perfusion relationship. The lung volume at which a small airway begins to close is called the closing capacity of the lung. If the functional residual capacity (ie, volume of air remaining in the lungs at the end of a normal expiration) is decreased below the closing capacity of the lung, regions with a low ventilation-perfusion ratio will develop, which leads to impaired gas exchange. The failure of closed airways to reopen leads to a total collapse of the lung unit served by the airway, producing atelectasis and a reduced SaO_2 value.[4-6,28]

The influence of modern anesthesiological,[8,29] analgesic,[5,30] and physiotherapeutic techniques[14] on postoperative pulmonary function after conventional abdominal surgery has been evaluated to reduce the high incidence of pulmonary complications after gastrointestinal tract resections. Pain relief or intensive physiotherapy has improved the postoperative recovery of pulmonary function only marginally.[5,10,30-32] A reduction of the functional residual capacity by 25%[30] and the FVC or FEV_1 by about 50% appears to be inevitable because the degree of diaphragmatic dysfunction after upper abdominal laparotomy cannot be substantially influenced. This reduction of the pulmonary function will cause atelectasis in more than 50% of patients,[3,4,6,23,25] and pneumonia will develop in up to 7% of patients after conventional colorectal resection, regardless of supportive therapy.[11-13]

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LAPAROSCOPIC SURGERY, however, may reduce the degree of diaphragmatic dysfunction and the incidence of pulmonary complications.[14,16] Residual pneumoperitoneum does not influence pulmonary function after diagnostic laparoscopy,[33] but changes in diaphragmatic function have been found after laparoscopic cholecystectomy.[34] After laparoscopic cholecystectomy, the FVC decreases to 54% to 79%, the FEV_1 to 54% to 80%, the PEF to 49% to 76%, and the $FEF_{25\%-75\%}$ to 68% to 88% of the preoperative value.[14,16,35,36] Furthermore, the total lung capacity is suppressed to 92% and the maximum minute ventilation to 78% of the preoperative values.[14]

Several randomized trials have proved that FVC, FEV_1, and $FEF_{25\%-75\%}$ values are suppressed by almost 50% after conventional cholecystectomy, whereas they are reduced by only 19% to 27% after laparoscopic gallbladder surgery.[14,16,35,37] The postoperative SaO_2 decreased one third less in a laparoscopic resection group than in a conventional resection group,[14,16] and there were significant differences in postoperative pulmonary function between the 2 groups, even when conventional cholecystectomy was performed by minilaparotomy.[16,35] Furthermore, the SaO_2, measured while patients were breathing room air, was significantly lower after conventional than after laparoscopic cholecystectomy.[14,16]

Few data have been available regarding postoperative pulmonary function after laparoscopic and conventional colectomy. Franklin et al[17] compared 84 laparoscopic and 110 conventional colorectal resections and found that "pulmonary toilet" was promoted after laparoscopic surgery. Senagore et al[11] described 5 cases of pneumonia (19%) after 26 laparoscopic colectomies and 11 cases of pneumonia (10%) after 110 conventional colorectal resections. All cases of pneumonia were diagnosed early in this series after surgery with a pneumoperitoneum of 15 mm Hg. Later, all resections were performed with an intra-abdominal pressure of 10 mm Hg, and no further patients with pulmonary infection were observed.[11] In our department, laparoscopic colorectal resections are performed with a maximum intra-abdominal pressure of 12 mm Hg, and after more than 100 laparoscopic colorectal procedures, no cases of pneumonia have developed.

Only 2 clinical trials[18,38] addressing pulmonary function after laparoscopic and conventional colorectal resection have been published. Azagra et al[18] performed laparoscopic proctosigmoidectomies in 7 patients using trocar positions comparable to those used in our technique. Postoperative changes in FVC, FEV_1, and PEF values after laparoscopic surgery were compared with those of laparoscopic-assisted (n = 7) and conventional (n = 7) proctosigmoidectomies. The authors did not find any significant difference in postoperative pulmonary function between the 2 groups. On the first postoperative day, the difference in PEF values between both groups was about 15%. This difference is almost identical to the difference in PEF values 24 hours after surgery in our trial (18.8%). To detect a 15% difference in PEF values between laparoscopic and conventional resections with a power of 80%, a sample size of 30 patients in each group would have been necessary.[19] Therefore, it can be assumed that Azagra et al[18] were not able to detect significant differences in pulmonary function after laparoscopic, laparoscopic-assisted, and conventional proctosigmoidectomy because of the small sample size of their study.

Stage et al[38] randomly assigned 29 patients from 3 different departments to laparoscopic (n = 15) or conventional (n = 14) colectomy and did not find any significant differences in pulmonary function between the groups. There are, however, some important differences between this study and our own trial. All patients investigated by these authors underwent perioperative thoracic epidural analgesia, which was not used in our trial. Almost 50% of their patients (n = 14) underwent an ascending colectomy, whereas 46 of our patients (77%) underwent proctosigmoidectomy, which is the most common laparoscopic and conventional colorectal cancer resection. Although no exact data for mean preoperative pulmonary function are given by Stage et al, and no SD is shown in the figures given, the preoperative pulmonary function seemed to be much worse in their study (FVC, 2.3-2.5 L; and FEV_1, about 1.8 L/s) than in our patients (preoperative FVC, 3.6 ± 1.3 L and 3.4 ± 1.0 L; and preoperative FEV_1, 2.6 ± 0.9 L/s and 2.4 ± 1.0 L/s). Although the mean patient age was about 10 years lower in our study, other factors might be responsible for this considerable difference in preoperative pulmonary function between the groups, and these may explain the different postoperative findings.

Our randomized study supports 3 theses reported by other authors: First, a wide midline laparotomy causes a postoperative depression of pulmonary function by 50% to 60%[3,5,6,23]; second, complete recovery of pulmonary function takes more than 7 days[3,4]; and third, significant decreases in SaO_2 values may occur several days after laparotomy, despite an uneventful course, suggesting the formation of atelectatic areas in the lung.[6] In contrast to the conventional resection group, pulmonary function was reduced by only 35% after laparoscopic colorectal resection. Furthermore, it recovered within 3 days, and the postoperative SaO_2 was almost unchanged in the laparoscopic resection group. However, although a greater initial diminution of pulmonary function occurred in patients undergoing conventional colorectal resection compared with those having laparoscopic surgery, the daily amount of pulmonary recovery was comparable in both groups. The previously suggested pathogenesis may explain why the SaO_2 was more severely reduced from day 1 to day 4 after conventional colorectal resection in our study. Lindberg et al[6] have shown a significant correlation between pulmonary function, atelectatic areas, and the PaO_2 value after conventional colorectal resection. Therefore, the differences in SaO_2 values between the groups in our study (Figure 4) indicate a greater impairment of functional residual capacity[14] and a higher incidence of atelectasis.[6,14] Furthermore, the lower levels of SaO_2 may indicate an increased risk for postoperative complications[16,23] after conventional than after laparoscopic surgery.

Clinical data from randomized trials[14,16] regarding pulmonary function after conventional and laparoscopic cholecystectomy support the assumption that the incidence of

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pneumonia may be reduced by laparoscopic surgery because radiological evidence of atelectasis occurred less often (40%) after laparoscopic than after conventional (90%) surgery, and the incidence of chest infection was higher after minilaparotomy (8%) than after laparoscopic cholecystectomies (1%). In our study, pneumonia developed in 2 patients (7%) after conventional colorectal resection, but not after laparoscopic surgery; this difference was not significant. Further randomized multicenter trials will need to evaluate whether the incidence of pneumonia is lower after laparoscopic colorectal resections than after conventional procedures.

The data of our randomized trial demonstrate that pulmonary function is 30% to 35% less suppressed and recovers 40% to 45% faster after laparoscopic surgery than after conventional colorectal resection. No other change in surgical, anesthesiological, or physiotherapeutic technique has resulted in such an improvement of postoperative pulmonary function after colorectal resection. Because of these major advantages, the use of the laparoscopic approach may decrease the incidence of postoperative pulmonary complications after elective colorectal resections. Therefore, laparoscopic resection should be considered in every patient scheduled for an elective segmental resection of benign colorectal disease. Laparoscopic procedures, however, cannot be recommended for the curative treatment of malignant disease, unless randomized multicenter studies have determined the long-term results of the new technique.

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Invited Critique

New surgical techniques invariably arrive amid a flurry of claimed advantages, often unsubstantiated. Laparoscopic colectomy is no exception, and surgical journals are replete with claims of an early return of gastrointestinal function, reduced pain, shorter lengths of stay, and decreased morbidity. Advocates of laparoscopic surgery have long argued that decreased postoperative pain leads to better pulmonary function, a finding borne out in comparative trials of open vs laparoscopic cholecystectomy.[1-3] In the preceding article, Schwenk et al address the issue of pulmonary function following large-bowel resection: Is the well-documented impairment of pulmonary function following conventional colectomy ameliorated by a laparoscopic approach?

Alterations in pulmonary function are common following abdominal surgery because of pain, central nervous system–depressant medications, muscle weakness, and elevation of the diaphragm. Reduced functional residual capacity, vital capacity, and forced expiratory volume in 1 second conspire to cause atelectasis, which is reported in varying percentages of patients but accounts for most pulmonary complications. Although atelectasis is usually of little clinical consequence, its presence sets the stage for a progression to pneumonia, which occurs in up to 5% of patients following abdominal surgery. Efforts to improve pulmonary function are ultimately directed at the prevention of pneumonia.

The present study is a well-designed, randomized controlled trial that demonstrates less impairment in pulmonary function following laparoscopic than open colectomy, findings that echo the results of previous cholecystectomy trials. How broadly applicable are the results, and what do they mean practically?

First, it is worth considering whether the patients with open colectomy received optimal management with respect to postoperative pulmonary function. Most patients studied underwent the resection of rectal or rectosigmoid lesions. One assumes that the authors' "wide midline laparotomy" includes extension of the incision into the upper abdomen in the group undergoing conventional resection. At our institution (Division of Colon and Rectal Surgery, University of Minnesota, Minneapolis), most sigmoid colectomies, anterior resections, and abdominoperineal resections are performed through either a transverse infraumbilical or a lower midline incision. Avoiding upper abdominal incisions may limit some of the detrimental effects of laparotomy on pulmonary function. Furthermore, although certainly not a uniform finding, improvement in pulmonary function with the use of epidural analgesia has been shown in several studies.[4-6] The authors note the conflicting results of the study by Stage et al,[7] which showed no significant difference in pulmonary function following laparoscopic or open colectomy, a study that, interestingly, used epidural analgesics for pain control in the group undergoing conventional colectomy. Perhaps a similar approach to pain management in the patients having open surgery in the present study would have mitigated their impaired pulmonary function.

Second, the authors have included few patients in their trial with underlying pulmonary disease, and none of their patients had severely compromised pulmonary function. Thus, those at highest risk for pulmonary complications were not part of the study population. In addition, severe chronic obstructive pulmonary disease can be a relative contraindication to laparoscopy. The Trendelenburg position and positive-pressure pneumoperitoneum can exacerbate the general anesthesia–associated decline in functional residual capacity, particularly in patients with chronic obstructive pulmonary disease, and carbon dioxide absorption can lead to hypercarbia, requiring increased ventilation.[8-10] Because of these issues, extrapolating the present results to high-risk patients must be undertaken with caution.

Most important, although the authors have clearly shown an improvement in pulmonary function test results, they have not demonstrated a significant difference in serious pulmonary morbidity—although, because of the overall low incidence of postoperative pneumonia following colectomy, a large trial would be necessary to demonstrate a significant difference between open and laparoscopic techniques with pneumonia as the primary end point.

The present study convincingly demonstrates less deterioration in pulmonary function following laparoscopic than conventional colectomy. Does this mean, as the authors state, that *every* patient scheduled for elective segmental resection of benign disease should be considered for laparoscopic resection? This far-reaching conclusion remains premature. Schwenk et al have clearly set a benchmark for postoperative pulmonary function using laparoscopic colectomy that optimized conventional surgery must now attempt to match. But whether improvement in this surrogate end point can be translated into a clinically significant improvement in outcome that justifies the additional operative time and cost of laparoscopy and whether the present results are applicable to patients at high risk for pulmonary complications await further study.

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