Maximal voluntary ventilation and forced vital capacity of pulmonary function are independent prognostic factors in colorectal cancer patients
A retrospective study of 2323 cases in a single-center of China

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Abstract
Preoperative pulmonary function assessment is applied to select surgical candidates and predict the occurrence of postoperative complications. This present study enrolled 2323 colorectal cancer patients. Forced vital capacity (FVC) and maximal voluntary ventilation (MVV) were measured as predicted values. Associations between patient pulmonary function and both prognosis and postoperative complications was analyzed. The value of FVC and MVV optimal cutoff was 98.1 (P < .001) and 92.5 (P < .001), respectively. Low FVC and low MVV were associated with higher rates of postoperative fever (23.8% vs 13.9%, P < .001: 17.8% vs 13.3%, P = .049, respectively) and with higher rates of pneumonia (3.75% vs 1.73%, P = .002; 3.00% vs 1.71%, P = .009, respectively), pleural effusion (3.00% vs 1.57%, P = .033; 3.18% vs 1.42%, P = .006, respectively), and poor patient prognosis (5-year overall survival: 80.0% vs 90.3%, P < .001; 71.7% vs 91.9%, P < .001, respectively). In addition, low FVC was closely related to the higher rate of anastomosis leak (4.31% vs 2.29%, P = .013), low MVV was correlated with the higher rate of uroschesis (2.38% vs 1.42%, P = .009), respectively. In subgroup analyses, the predictive value of FVC and MVV in patients with different tumor stage was analyzed. Both low FVC and MVV were independent risk factors for poor prognosis in stage II and III, indicating that low FVC and MVV are predictive of poorer prognosis and higher risk of postoperative complications in colorectal cancer patients.

Abbreviations: CRC = colorectal cancer, FEV1 = forced expiratory volume 1, FVC = forced vital capacity, MVV = maximal voluntary ventilation, OS = overall survival, ROC = receiver operating characteristic curve.

Keywords: colorectal cancer, maximal voluntary ventilation, pulmonary function, retrospective cohort, survival

1. Introduction
Colorectal cancer (CRC) is the third most commonly diagnosed cancer and the fourth leading cause of cancer death in the world.[1] Despite the rising incidence in several countries, CRC mortality rate is decreasing in many countries worldwide, due to the screening and improved surgical therapy.[2,3] Surgeons commonly encounter patients suffering from impaired pulmonary function during preoperative evaluation. Postoperative pulmonary complications account for a substantial portion of the risks that are related to surgery and anesthesia and are a source of postoperative morbidity, mortality, and longer hospital stays.[4] Therefore, pulmonary function testing is widely applied to select surgical candidates and predict the occurrence of postoperative respiratory complications,[5] and it is even more likely than cardiac complications to predict long-term mortality after surgery.[6] Some studies also revealed the influence of pulmonary function on abdominal surgery outcomes.[7,8] It is difficult to diagnose pulmonary disease clinically, unless a patient presents overt respiratory symptoms. Therefore, preoperative screening for pulmonary disease usually depends on a given patient’s previous medical history.[9] In terms of evaluating pulmonary abnormalities and predicting postoperative complications, preoperative screening using pulmonary function testing is likely to be more valuable than conventional assessment.[6] Although preoperative pulmonary function testing is accepted as an effective tool to predict operative risk before thoracic surgery,[8]
it is not yet routinely performed for colorectal cancer patients before surgery. However, the prognostic value of preoperative pulmonary function in CRC patients was often less investigated. The purpose of this retrospective study was to estimate the value of pulmonary function of CRC patients before surgery and to assess whether it has a prognostic value and the likelihood of postoperative complications.

2. Materials and methods

2.1. Patient selection

The retrospective study enrolled 2323 patients who were diagnosed with CRC and treated surgically between June, 2011 and December, 2016 at Division of Gastrointestinal Surgery, First Affiliated Hospital of Air Force Military Medical University. Enrolled patients were histologically confirmed and without distant metastasis. Patients with one of the following features, including (stage IV) CRC with more than one primary cancer, and with R1 or R2 resection, were excluded from our study. Other patients with missing data were also excluded. When the following data were available, patients were only considered eligible. According to the World Health Organization criteria, tumor differentiation grades were defined. Cancer staging was based on the American Joint Committee on Cancer Staging system (AJCC, 2002; Greene, American Joint Committee on Cancer, American Cancer Society, 2002). Pulmonary function test was carried out <7 days before surgery. FVC and MVV were measured by spirometry and as a percent of predicted values. The study was approved by the ethics committee of First Affiliated Hospital of Air Force Military Medical University. All patients provided written consent for storage of their information in the hospital database, and for the research use of the information.

2.2. Follow-up and outcome

Each patient was followed up periodically until death or April 2017 (every 3 months for the first 2 years, and every 6 months up to the fifth year) after surgery. The follow-up cycles varied from 3 to 6 months, with a median of 66.3 months. The follow-up visits consisted of a physical examination and laboratory studies at least every 6 months or when clinically indicated. The endpoint of the study was overall survival (OS). OS was calculated as the period from the date of diagnosis to the date of death from any cause or the date of last follow-up. Survival status was verified again by adopting the best available methods, including checking clinical attendance records and direct telecommunication with the patients or their families.

2.3. Statistical analysis

Chi-square test was conducted to compare categorical variables. Receiver operating characteristic curve (ROC) curve analysis was carried out to determine optimal cutoff values of FVC and MVV. If they have no homogeneity of variance, Kruskal Wallis test would be used. The survival rate was evaluated by Kaplan-Meier survival analysis, and their significance was calculated by the log-rank test. Univariate and multivariate Cox regression analyses were performed. Multivariable analyses were performed for factors that were significantly associated with OS in univariate analyses. All the statistical analyses were conducted using IBM SPSS 22.0 software. P value < .05 was considered to be statistically significant.

3. Results

Our study involved 1080 men (46.5%) and 1243 women (53.5%) CRC patients (Table 1). Median patient age was 59 years (range, 19–86), and median follow-up time was 28 months (range, 1–67). Patient 1-, 3-, and 5-year OS rates were 94.6%, 87.2%, and 85.5%, respectively (Fig. 1).

FVC and MVV optimal cutoff values were 98.1 (P < .001) and 92.5 (P < .001) respectively (Fig. 2). Baseline characteristics of patients with low (FVC < 98.1, MVV < 92.5) versus high (FVC > 98.1, MVV > 92.5) FVC and MVV levels were analyzed and shown in Table 1. We discovered that lower FVC level was associated with female (χ² = 8.953, P = .003), advanced age (χ² = 21.626, P < .001), abnormal body-mass index (χ² = 7.362, P = .025), abnormal total protein (χ² = 5.099, P = .024), hypoproteinemia (χ² = 7.257, P = .007), tumor location (χ² = 79.353, P < .001), large tumor size (χ² = 6.743, P = .009), advanced tumor depth (χ² = 9.491, P = .023), poorly differentiated pathology type (χ² = 6.593, P = .037) and advanced tumor stage (χ² = 14.027, P = .001). lower MVV level was closely related to female (χ² = 66.993, P < .001), advanced age (χ² = 13.992, P < .001), abnormal body mass index (χ² = 9.444, P = .009), abnormal total protein (χ² = 16.141, P < .001), hypoproteinemia (χ² = 7.746, P = .003), tumor location (χ² = 54.734, P < .001), large tumor size (χ² = 6.141, P = .013), advanced tumor depth (χ² = 9.170, P = .027), poorly differentiated pathology type (χ² = 33.387, P < .001), advanced lymph node metastasis (χ² = 16.233, P < .001), and advanced tumor stage (χ² = 14.965, P = .001) (Table 1).

Our results proved that low FVC (P < .001) and MVV (P < .001) were correlated with poor prognosis in CRC patients (Fig. 3). A univariate analysis demonstrated that tumor location, pathological type, tumor depth, tumor stage, FVC, MVV, total protein, and albumin were associated with prognosis (Table 2). Meanwhile, tumor depth, tumor stage, FVC, and albumin were independent prognostic predictors (Table 2). Subsequently, we then analyzed the predictive value of FVC and MVV in patients at different tumor stages. Both MVV and FVC were not related to prognosis in stage I CRC cases. However, low MVV and FVC were correlated with poor prognosis in patients at stage II and III colorectal cancer (Figs. 4 and 5). Univariate and multivariate analyses displayed that FVC and MVV was an independent risk factor for prognosis at stage II (Table 3) and III (Table 4) CRC patients.

Finally, we analyzed the relationships between FVC and MVV levels and postoperative complications (Table 5). Low FVC and low MVV indicate higher rates of pneumonia (3.75% vs 1.73%, P = .002; 3.00% vs 1.71%, P = .009, respectively), pleural effusion (3.00% vs 1.57%, P = .033; 3.18% vs 1.42%, P = .006, respectively). In addition, low FVC refers to a higher rate of anastomosis leak (4.31% vs 2.29%, P = .013) and low MVV represents a higher rate of urosechisis (2.38% vs 0.65%, P < .001).

4. Discussion

The association among preoperative pulmonary function and postoperative pulmonary complications and patient mortality have been well investigated. Feng et al[9] reported that pulmonary disease was associated with postoperative morbidity in a large, multicenter, laparoscopic gastrectomy study. Jeong et al[12] revealed that preoperative pulmonary function testing effectively predicted the risk of surgical complications and systemic complications in patients undergoing gastrectomy. The
prognostic value of preoperative pulmonary function has mainly been investigated in thoracic surgery.\cite{7} Guo et al\cite{11} proved that FVC was an independent risk factor for the prognosis of non-small cell lung cancer patients who experienced curative resection, and FVC $<80\%$ predicted poor patient survival. Matsuzaki et al\cite{10} discovered that low forced expiratory volume 1 (FEV1)/FVC ratios with reduced overall and disease-free survival in lung cancer patients undergoing thoracic surgery. The same group revealed that the carbon monoxide diffusing capacity of the lung and the inspiratory capacity/total lung capacity ratio were associated with patient prognosis.\cite{10} However, the prognostic value of preoperative pulmonary function in colorectal cancer patients was rarely investigated. Sagawa et al\cite{13} illustrated that pulmonary dysfunction function is a risk factor for remote infections following surgery for CRC. Our study demonstrated that low FVC and MVV are related to poor prognosis in CRC patients, and both of them were independent prognostic predictors.

FVC is the ratio of actual vital capacity to predict vital capacity, and a FVC $<80\%$ is associated with restraint disorder.\cite{13} FVC reflects an individual’s potential abilities such as exercise capacity,\cite{13} and values lower than 80% indicate the presence of restrictive impairment.\cite{13} The decreases in FVC postoperatively in patients who have preoperative restrictive impairment suggest that they may have developed a severe pulmonary complication. Particularly, atelectasis occurs due to suppressed deep breathing from pain. Tajima et al\cite{14} displayed that FVC may be a predictor of postoperative complications, especially pneumonia in colorectal cancer surgery. Multiple groups investigated the association between FVC and survival in the general population.\cite{13,16} Burnery et al\cite{16} reported that FVC, but not airway obstruction, can predict survival in asymptomatic adults without chronic respiratory

| Table 1 | Baseline characteristics of patients with low versus high FVC and MVV levels. |
|---------|-------------------------------------------------------------|
|         | FVC | MVV                                          |
| Patient characteristics | Low FVC | High FVC | F value | P value | Low MVV | High MVV | F value | P value |
| Gender  |        |        |         |         |        |         |         |         |
| Male    | 218   | 862   | 8.953   | .003    | 205    | 875     | 66.993  | <.001   |
| Female  | 316   | 927   |         |         | 424    | 819     |         |         |
| Age, y  |        |        |         |         |        |         |         |         |
| $<60$   | 238   | 1002  | 21.626  | <.001   | 376    | 864     | 13.992  | <.001   |
| $\geq60$| 296   | 787   | 7.362   | .025    | 253    | 828     | 9.444   | .009    |
| BMI     |        |        |         |         |        |         |         |         |
| $<18.5$ | 84    | 236   |         |         | 101    | 219     |         |         |
| $\geq18.5$–$<25.0$ | 328   | 1212  | 386     | 1154    | 142    | 321     | 9.144   | .001    |
| $\geq25.0$ | 122  | 341   |         |         | 331    | 734     | 9.444   | .001    |
| Total protein |      |        |         |         | 5.099  | .024    | 16.141  | <.001   |
| $<65.0$ | 312   | 946   |         |         | 298    | 962     |         |         |
| $\geq65.0$ | 222 | 843   |         |         | 331    | 734     | 5.437   | .027    |
| Albumin |        |        |         |         | 7.257  | .007    | 7.746   | .005    |
| $<40.0$ | 328   | 981   |         |         | 384    | 925     |         |         |
| $\geq40.0$ | 206 | 808   |         |         | 245    | 769     | 5.437   | .027    |
| Tumor location$^d$ | |        |         |         | 79.353 | <.001   | 54.734  | <.001   |
| Right hemicolon | 142 | 419   |         |         | 128    | 433     |         |         |
| Left hemicolon | 138 | 206   |         |         | 149    | 195     |         |         |
| Rectum $<6$cm | 108 | 406   |         |         | 150    | 454     |         |         |
| Rectum $\geq6$cm | 146 | 668   |         |         | 202    | 612     |         |         |
| Tumor size, cm | |        |         |         | 6.743  | .009    | 6.141   | .013    |
| $\leq5$ | 256   | 972   |         |         | 359    | 869     |         |         |
| $>5$    | 278   | 817   |         |         | 270    | 825     | 33.387  | <.001   |
| Pathology type | |        |         |         | 6.593  | .037    |         |         |
| Well differentiated | 157 | 563   |         |         | 198    | 522     |         |         |
| Moderately differentiated | 159 | 434   |         |         | 209    | 384     |         |         |
| Poorly differentiated | 218 | 792   |         |         | 222    | 788     | 9.417   | .027    |
| pT status | |        |         |         | 9.491  | .023    | 9.170   | .027    |
| pT1     | 47    | 238   |         |         | 82     | 203     |         |         |
| pT2     | 71    | 265   |         |         | 105    | 231     |         |         |
| pT3     | 181   | 563   |         |         | 213    | 531     |         |         |
| pT4     | 235   | 723   |         |         | 229    | 729     |         |         |
| pN status | |        |         |         | 5.522  | .063    | 16.233  | <.001   |
| pN0     | 165   | 540   |         |         | 182    | 523     |         |         |
| pN1     | 221   | 662   |         |         | 209    | 674     |         |         |
| pN2     | 148   | 587   |         |         | 238    | 497     |         |         |
| pTNM stage | |        |         |         | 14.027 | .001    | 14.965  | .001    |
| Stage I | 113   | 526   |         |         | 210    | 429     |         |         |
| Stage II| 190   | 565   |         |         | 189    | 566     |         |         |
| Stage III | 231 | 698   |         |         | 230    | 699     |         |         |

FVC = forced vital capacity, MVV = maximal voluntary ventilation.
diagnoses or persistent respiratory symptoms. Low FVC was closely related to increased mortality risk.\textsuperscript{[17]} We proposed 2 possible explanations for these findings, both of which strengthened the case for using pulmonary function testing in gastric cancer patients prior to surgery. First, pulmonary function tests may reflect muscle strength and general energy levels, and physical and psychological disorders may manifest as lower values. Therefore, these tests may indicate an individual patient’s overall health.\textsuperscript{[17]} In these cases, FVC may reflect overall cardiopulmonary function as well as general health.

MVV is a pulmonary function test, and it can measure the maximum amount of air a person can inhale and then exhale with voluntary effort.\textsuperscript{[20]} In addition to the well-recognized clinicopathological prognostic factors, recent studies focused on identifying new factors, which can be highly reproducible, easily obtainable, inexpensive and reliable. We provided two possible explanations for these findings, both of which strengthened the case for using pulmonary function testing in gastric cancer patients prior to surgery. First, pulmonary function tests may reflect muscle strength and general energy levels, and physical and psychological disorders may manifest as lower values. Thus, these tests may indicate an individual patient’s overall health. Second, poor fetal growth rates and lower birth weights may result in reduced lung function and increased risk of cardiovascular disease.\textsuperscript{[18,19]} In these cases, MVV may reflect overall cardiopulmonary function and general health as well.

Given the high operative mortality rate after surgery for CRC among patients who develop infectious complications. It was found that low FVC is related to pneumonia, pleural effusion and anastomosis leak, which may lead to severe abdominal infection. Preoperative pulmonary function is included in the risk score of the estimation of physiologic ability and surgical stress scoring system for the assessment of surgical risk proposed by Mcmillan\textsuperscript{[21]} with the reference values of FVC <60% and/or FEV1.0% <50%. Although these values are stricter than those applied in the present study, pulmonary function was a risk factor for postoperative complications. We hypothesized that pulmonary dysfunction can cause pulmonary complications and an oxygen supply disorder, and circulatory disorders might make it difficult to supply sufficient energy for tissue repair. As a result, patients suffering from pulmonary dysfunction might develop anastomosis leak at a high rate.

There were several limitations in our present study. Firstly, it was a retrospective analysis and limited to a single center. Multicenter studies are needed to verify the predictive value of MVV. Secondly, our patient cohort was not large enough, and small sample sizes can result in biased statistical analyses. Thirdly, postoperative pulmonary function may play roles in gastric cancer patient prognosis, and should be explored.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Overall survival of colorectal cancer patients.}
\end{figure}
Figure 2. Optimal cutoff values of FVC and MVV were determined by ROC curve analysis. FVC = forced vital capacity, MVV = maximal voluntary ventilation, ROC = receiver operating characteristic curve.

Figure 3. Patient overall survival based on FVC and MVV level. FVC = forced vital capacity, MVV = maximal voluntary ventilation.

Table 2

Univariate and multivariate Cox regression analysis for overall survival in patients with colorectal cancer.

| Characteristics | Univariate analysis | Multivariate analysis |
|-----------------|--------------------|----------------------|
|                 | HR                 | 95% CI               | P      | HR | 95% CI | P   |
| Gender          |                    |                      |        |    |        |     |
| Male            | 1.00               | Reference            | .427   | —  | —      | —   |
| Female          | 1.094              | 0.876–1.366          |        | —  | —      | —   |
| Age (years)     |                    |                      |        |    |        |     |
| <60             | 1                  | Reference            | .516   | —  | —      | —   |

(continued)
Table 2  
(continued).

| Characteristics | Univariate analysis | Multivariate analysis |
|-----------------|---------------------|-----------------------|
|                 | HR                  | 95% CI                | P        | HR                  | 95% CI                | P        |
| ≥60             | 0.930               | 0.746–1.159           | 0.043    | —                   | —                    | —        |
| Location        |                     |                       |          |                     |                      |          |
| Right hemicolon | 1                   | Reference             | 1        | Reference           | 1                    | Reference |
| Left hemicolon  | 0.683               | 0.499–0.935           | 0.695    | 0.513–0.943         |                      |          |
| Rectum (≥6 cm)  | 0.922               | 0.668–1.272           | 0.928    | 0.673–1.278         |                      |          |
| Rectum (<6 cm)  | 1.057               | 0.781–1.431           | 1.046    | 0.774–1.415         |                      |          |
| Tumor size, cm  |                     |                       |          |                     |                      |          |
| <5              | 0.936               | 0.730–1.200           | 0.018    | 0.648               | 0.437–0.962          | 0.052    |
| >5              | 1                   | Reference             | 1        | Reference           | 1                    | Reference |
| Pathology (adenocarcinoma) |     |                       |          |                     |                      |          |
| Well differentiated | 0.657               | 0.442–0.979           | 0.648    | 0.437–0.962         |                      |          |
| Moderately differentiated | 0.690               | 0.528–0.901           | 0.683    | 0.530–0.898         |                      |          |
| Poorly differentiated | 1               | Reference             | 1        | Reference           | 1                    | Reference |
| pT status       |                     |                       |          |                     |                      |          |
| pT1             | 0.244               | 0.089–0.668           | 0.318    | 0.142–0.713         |                      |          |
| pT2             | 0.394               | 0.211–0.734           | 0.475    | 0.306–0.736         |                      |          |
| pT3             | 0.641               | 0.487–0.842           | 0.618    | 0.472–0.808         |                      |          |
| pT4             | 1                   | Reference             | 1        | Reference           | 1                    | Reference |
| pN status       |                     |                       |          |                     |                      |          |
| pN0             | 1.00                | Reference             | 1        | Reference           | 1                    | Reference |
| pN1             | 1.009               | 0.329–3.099           | 0.667    | 0.268–1.663         |                      |          |
| pN2             | 0.883               | 0.617–1.262           | 0.726    | 0.530–0.898         |                      |          |
| pTNNM stage     |                     |                       |          |                     |                      |          |
| Stage I         | 0.538               | 0.218–1.330           | 0.390    | 0.292–0.520         |                      |          |
| Stage II        | 0.695               | 0.532–0.908           | 0.695    | 0.533–0.905         |                      |          |
| Stage III       | 1                   | Reference             | 1.00     | Reference           | 1                    | Reference |
| FVC             |                     |                       |          |                     |                      |          |
| Low             | 1.00                | Reference             | 1        | Reference           | 1                    | Reference |
| High            | 0.883               | 0.617–1.262           | 0.726    | 0.530–0.898         |                      |          |
| MVV             |                     |                       |          |                     |                      |          |
| Low             | 1.00                | Reference             | 1        | Reference           | 1                    | Reference |
| High            | 0.795               | 0.634–0.997           | 0.896    | 0.834–0.980         |                      |          |
| BMI             |                     |                       |          |                     |                      |          |
| <18.5           | 1.105               | 0.566–0.901           | 0.951    | 0.817–1.062         |                      |          |
| ≥18.5–<25.0     | 0.951               | 0.817–1.062           | 0.951    | 0.817–1.062         |                      |          |
| ≥25.0           | 1                   | Reference             | 1        | Reference           | 1                    | Reference |
| Albumin         |                     |                       |          |                     |                      |          |
| ≥40.0           | 0.713               | 0.558–0.911           | 0.685    | 0.559–0.911         |                      |          |
| <40.0           | 1                   | Reference             | 1        | Reference           | 1                    | Reference |
| Total protein   |                     |                       |          |                     |                      |          |
| ≥65.0           | 0.528               | 0.390–0.714           | 0.825    | 0.794–0.920         |                      |          |
| <65.0           | 1                   | Reference             | 1        | Reference           | 1                    | Reference |

CI = confidence interval, FVC = forced vital capacity, HR = hazard ratio, MVV = maximal voluntary ventilation.

Figure 4. Overall survival of patients in different tumor stages based on FVC level. FVC = forced vital capacity.
Table 3
Univariate and multivariate analysis of risk factors for prognosis of stage II colorectal cancer.

| Prognostic factors | Univariate analysis | Multivariate analysis |
|--------------------|---------------------|-----------------------|
|                    | β       | HR (95% CI) | P   | β       | HR (95% CI) | P   |
| Gender             | 0.312   | 1.366 (0.893–2.090) | .150 | 0.244   | 1.276 (0.841–1.937) | .252 |
| Age                | 0.202   | 1.224 (0.813–1.842) | .004 | 0.656   | 0.59 (0.274–0.984)  | .45  |
| Location           | −0.825  | 0.438 (0.270–0.710) | .001 | −0.671  | 0.45 (0.243–0.844)  | .010 |
| Tumor size         | 0.343   | 1.409 (0.918–2.165) | .117 | 0.322   | 0.910 (0.317–2.508) | .795 |
| Pathology          | −0.163  | 0.849 (0.393–1.836) | .678 | 0.372   | 0.919 (0.328–2.514) | .840 |
| pt status          | −0.918  | 0.399 (0.241–0.662) | <.001 | 0.387   | 0.672 (0.249–1.976) | .481 |
| pN status          | 0.252   | 0.8281 (0.492–0.975) | .325 | 0.388   | 0.913 (0.517–1.620) | .766 |
| FVC                | 0.788   | 2.198 (1.448–3.337) | <.001 | 0.765   | 2.149 (1.401–3.298) | .001 |
| MVV                | 0.331   | 0.784 (0.478–0.780) | <.001 | 0.358   | 0.882 (0.517–1.567) | .017 |
| BMI                | −0.301  | 1.203 (0.764–1.625) | .784 | −0.038  | 1.067 (0.991–1.145) | .313 |
| Albumin            | 0.082   | 0.957 (0.742–1.236) | .021 | 0.321   | 1.288 (0.834–1.973) | .032 |
| Total protein      | −0.038  | 0.824 (0.635–1.125) | .642 |          |              |      |

BMI = body mass index, CI = confidence interval, FVC = forced vital capacity, HR = hazard ratio, MVV = maximal voluntary ventilation.

Table 4
Univariate and multivariate analysis of risk factors for prognosis of stage III colorectal cancer.

| Prognostic factors | Univariate analysis | Multivariate analysis |
|--------------------|---------------------|-----------------------|
|                    | β       | HR (95% CI) | P   | β       | HR (95% CI) | P   |
| Gender             | −0.038  | 0.963 (0.757–1.225) | .059 | −0.290  | 0.748 (0.521–1.076) | .040 |
| Age                | −0.208  | 0.972 (0.766–1.233) | .072 | −0.091  | 0.913 (0.696–1.197) | .509 |
| Location           | 0.327   | 1.067 (0.764–1.490) | .007 | 0.388   | 0.669 (0.425–1.052) | .007 |
| Tumor size         | −0.224  | 0.800 (0.620–1.031) | .005 | −0.091  | 0.913 (0.696–1.197) | .509 |
| Pathology          | 0.665   | 0.514 (0.331–0.799) | .003 | −0.091  | 0.913 (0.696–1.197) | .509 |
| pt status          | −0.369  | 0.691 (0.531–0.900) | .006 | −0.709  | 0.492 (0.271–0.894) | .020 |
| pN status          | −0.570  | 0.566 (0.445–0.719) | <.001 | −0.471  | 0.624 (0.487–0.801) | .001 |
| FVC                | 1.283   | 1.109 (0.768–1.704) | <.001 | 1.143   | 1.136 (0.897–1.896) | <.001 |
| MVV                | 0.331   | 1.084 (0.878–1.320) | <.001 | 1.265   | 1.145 (0.755–1.778) | <.001 |
| BMI                | −0.545  | 1.124 (0.874–1.468) | .482 |          |              |      |
| Albumin            | 0.172   | 0.757 (0.442–1.026) | .042 | −0.154  | 0.586 (0.373–0.894) | .082 |
| Total protein      | −0.385  | 0.784 (0.438–1.052) | .534 |          |              |      |

BMI = body mass index, CI = confidence interval, FVC = forced vital capacity, HR = hazard ratio, MVV = maximal voluntary ventilation.

Table 5
Comparison of postoperative complications.

| Complications | FVC | MVV |
|---------------|-----|-----|
|               | ≤98.1 | >98.1 | χ² | P       | ≤92.5 | >92.5 | χ² | P       |
|               | n=534 | n=1789 |  |  | n=1694 | n=265 |  |  |
| Total cases   | 116  | 287  | 9.254 | .002 | 138  | 265  | 12.681 | <.001 |
| Pneumonia     | 20   | 31   | 7.757 | .005 | 22   | 29   | 6.812  | .009  |
| Pleural effusion | 16 | 28 | 4.533 | .033 | 20 | 24 | 7.671  | .006  |

(continued)
Table 5

(continued.)

| Complications                  | FVC ≤98.1 n=534 | FVC >98.1 n=1789 | χ²  | P     | MVV ≤92.5 n=629 | MVV >92.5 n=1694 | χ²  | P     |
|-------------------------------|----------------|------------------|-----|-------|----------------|------------------|-----|-------|
| Wound infection               | 20             | 45               | 2.287 | .130  | 13             | 52               | 1.696 | .193  |
| Fever                         | 17             | 87               | 2.713 | .100  | 28             | 76               | 0.001 | .971  |
| Anastomosis leak              | 23             | 41               | 6.234 | .013  | 20             | 44               | 0.580 | .446  |
| Anastomosis bleeding          | 4              | 14               | 0.006 | .938  | 6              | 12               | 0.360 | .549  |
| Chyle leakage                 | 6              | 12               | 1.096 | .295  | 6              | 7                | 2.409 | .121  |
| Anastomosis leak              | 7              | 19               | 2.287 | .130  | 13             | 52               | 1.696 | .193  |

FVC = forced vital capacity, MVV = maximal voluntary ventilation.

In conclusion, our study demonstrated that low FVC and MVV were closely related to poor prognosis in colorectal cancer patients, and FVC and MVV were independent prognostic predictors.

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