Development and Validation of a Nomogram for Predicting Overall Survival In Synchronous Peritoneal Metastasis of Colorectal Cancer

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Abstract

Background: Synchronous peritoneal metastases (PM) is a difficult issue to tackle and the prognosis is poor. The aim of this study is to construct a nomogram to predict the overall survival (OS) for synchronous colorectal peritoneal metastasis.

Method: In this retrospective study, 332 patients with synchronous PM were included. The training cohort consisting of 251 patients underwent abdominal surgery from February 2007 to February 2018. The risk factors related to prognosis were analyzed by Kaplan-Meier curve and Cox regression model. 81 patients from other two hospitals were enrolled as validation cohort. The prediction effect of this nomogram was evaluated by C-index and the calibration curve.

Result: Five predictors were enrolled into this nomogram after multivariate analysis, including age, peritoneal cancer index (PCI), completeness of cytoreductive surgery (CRS), CA19-9, and albumin. The nomogram showed the accuracy to predict the OS at 0.5, 1, 2, and 3 years. The C-index of the nomogram in the training cohort and validation cohort were 0.713 (95% CI, 0.674–0.752) and 0.642 (95% CI, 0.563–0.720) separately. Both training and validation cohorts showed good discrimination of the nomogram for OS. Calibration curves have shown the predicted OS of nomogram are consistent with actual survival.

Conclusion: This novel nomogram, combined with age, PCI, CRS, CA19-9, and albumin, has shown good accuracy to predict OS in patients with synchronous PM, which could be used as an easy-to-use tool for clinicians and surgeons to make decisions.

Background

Colorectal cancer (CRC) is one of the major cancer-related death in world, and peritoneal metastasis (PM) were presented in approximately 11–20% of CRC patients\(^1\). Synchronous PM was defined as colorectal cancer patients who have PM within 6 months at diagnosis of primary tumor, which is considered to be the last stage of CRC and is associated with poor prognosis in many studies\(^2\)\(^3\). Due to worse prognosis of PM compared to other organ metastasis, PM is classified as M1c of T4 stage (metastasize to the peritoneal surface with or without other organ) the National Comprehensive Cancer Network (NCCN) guideline (Version 1, 2020)\(^4\). The mean OS of M1c patients were only 5.2 months, which was lower than M1a or M1b\(^5\).

Sugarbaker, who created cytoreductive surgery (CRS) for PM, reported 50% of survival rate in colon cancer with peritoneal cancer index (PCI) < 10\(^6\). However, early diagnosis of PM is often inaccurate or even overdiagnosis. For the last decade, there were many reports on the treatments for PM, including CRS, hyperthermic intraperitoneal chemotherapy (HIPEC), neoadjuvant chemotherapy combined with targeted drugs, systemic chemotherapy, and the combination treatment plan\(^7\)\(^8\)\(^9\). Complete CRS requires resection of both the tumor and the entire peritoneum (peritoneal stripping surgery). CRS can remove all macroscopic tumor and prolong the median survival time of patients with PM. The operation is extensive.
and traumatized, so the morbidity and mortality are relatively high, and recurrences are common. The long-term survival rate has not increased as expected\textsuperscript{10}. Most PM treatment targets are palliative rather than curative according to NCCN guidelines (Version 1, 2020), mainly including systemic treatment and no standard scheme. An experienced center may consider surgical R0 removal of isolated peritoneal disease\textsuperscript{4}.

Peritoneal Surface Disease Severity Score (PSDSS), a prognostic score was introduced by Pelz at cl. to assess the extent of carcinomatosis, which based on clinical symptoms, PCI and primary tumor pathology. Patients with stage IV of PSDSS was obtain survival benefits from CRS and HIPEC treatment. PSDS IV reflects biologically invasive cancer, with a 2.6-fold increase in mortality\textsuperscript{11}. Another prognostic score named Colorectal Peritoneal Metastases Prognostic Surgical Score (COMPASS) was a new score of prognoses based on age, PCI, lymph nodes and the histology of signet ring cells, which shows better discriminative ability than PSDSS\textsuperscript{12}.

Synchronous PM is difficult to be diagnosed preoperatively by current imaging tools including CT scans, MRI imaging or even PET-CT scans\textsuperscript{13}. The tools and models to predict survival of PM are also lacking. Nomogram is a novel model through combining many prognostic factors by mathematical algorithm to predict survival of PM in recent years. It has been used in a variety of malignancies, including lung, stomach, esophageal carcinoma\textsuperscript{14–16}. In this study, we have included some of factors that were identified in the COMPASS model. We have constructed a new nomogram to predict the survival of PM in CRC to help clinicians to make decisions in clinical practice and cancer surveillance.

**Methods**

**Patients cohorts**

We have enrolled patients of synchronous PM from February 2007 to February 2018 at the hospital where the researchers were based. Those patients were taken as the training cohort. Patients originated of appendiceal cancer or lacking of follow up were excluded. Patients with the missing data of major variables are excluded. The clinicopathological data of all patients were retrieved from a prospective CRC database. An external independent validation cohort composed of 81 patients from other two hospitals were utilized to verify the nomogram. Overall survival (OS) was defined as the time from the diagnosis of synchronous peritoneal metastasis of colorectal cancer to the death. Our study was approved by the local Ethics Committee.

**Variables and Definitions**

Refer to risk factors that may be related to PM in previous literature and reported models, we examined the following variables for associations with OS by univariate analysis: age (continuous), gender, body mass index (BMI; continuous)\textsuperscript{17}, PCI(continuous)\textsuperscript{12}, CRS, HIPEC (yes, no)\textsuperscript{18}, Location of primary tumor (left-sided, right-sided), differentiation\textsuperscript{19}, presence of liver or lung metastasis\textsuperscript{20}, and laboratory markers
including hemoglobin, ALB, CA19-9, CA125 and CEA\textsuperscript{21}. All variables in this study were converted into binary variables based on the commonly used clinical cutoffs or the cutoffs provided by relevant literature. Among them, PCI was divided by cut-off point of 16 that was analyzed by the X-tile software (chi-sq Hi/Lo = 22.85, \(P< 0.01\)). CRS was converted into two groups according to the completeness of cytoreductive surgery (CC): CC 0–1 represents complete CRS of PM, and CC 2–3 was defined as those patients underwent incomplete CRS or received no CRS. The differentiation of tumor was also converted into two groups: poor-differentiated group represents patients with mucinous adenocarcinoma or signet ring cell carcinoma or poorly differentiated cancer, good-differentiated group consists of patients with moderate to well differentiated, or other pathological types of cancer.

**Tests for Two-Way Interactions**

To determine whether the effects of any covariates were dependent on other covariates, all pairs of variables with statistical significance in univariate analysis were tested for two-way interaction. Significant interaction (\(P< 0.001\)) and clinically differentiable effect mediation were required for subsequent consideration in final models. Higher ordered interactions were not tested for interpretability and reproducibility.

**Construction of the Nomogram**

Based on the results of multivariable analysis of Cox regression model, the nomogram is constructed with the “rms” and “survival ROC” package in R software studio to visualize Cox regression model. The individual prognosis score and 0.5-, 1-, 2-, and 3-year survival probability were calculated directly based on the nomogram. The predictive performance of the nomogram was evaluated using the concordance index (C-index) and calibration curves. The value of the C-index ranges from 0.5 to 1.0. Briefly, 0.5 indicated a random chance and 1.0 indicated a perfect ability to correctly discriminate the outcome with the model\textsuperscript{22}.

**Validation and Calibration Curve**

The nomogram was subjected to 1,000 bootstrap resamples for validation of the training cohort and the validation cohorts. Calibration curves of the nomogram for 0.5-, 1-, 2-, and 3-year OS were performed with R software by comparing the mean predicted survival rate with the mean actual survival rate determined using a Kaplan–Meier analysis after grouping the nomogram-predicted OS. In a perfectly calibrated model, predictive rates would fall on a 45-degree diagonal line.

**Statistical Analysis**

All binary variables were calculated by the Kaplan–Meier method and the log-rank test. Log-rank tests were applied to determine univariate prognostic factors. A multivariate Cox proportional hazards model was applied to estimate the independent effects of prognostic factors of OS. The independent prognostic factors by the multivariate analysis were used to construct the nomogram for OS. SPSS v23.0 (IBM, USA) statistical software and R software were used for all statistical analysis in this study. All P values were two-sided, and those variables with \(P < 0.05\) were considered to be statistically significant.
Results

A total of 332 patients were analyzed in this retrospective study. All patients underwent surgical exploration and were scored of PCI intraoperatively. There were 127 women (38.2%) and 205 men (61.8%). The median age was 56 (interquartile range = 45.25-67) years. The preoperative CA19-9 was > 37 g/L in 140 patients (42.2%), and preoperative albumin was < 35 g/L in 84 patients (25.3%). There were 221 PM patients (66.6%) combined with liver or lung metastasis. The median PCI score was 12 (interquartile range = 6–26) points, and there were 150 cases (45.2%) with PCI score > 16. In the patients who underwent CRS, 49 patients (14.8%) received complete CRS of PM with CC 0–1, and 85.2% of 283 patients (85.2%) underwent incomplete CRS of CC 2–3. There were 63 patients (19%) who underwent HIPEC plus postoperative adjuvant chemotherapy. The characteristics in the training and validation cohorts were shown in Table 1. The median follow-up time was 13.6 months (range from 1 to 60 months). The median OS was 15.6 months (95% CI: 12.4–19.6 months). Overall, the baseline characteristics were similar between the training and validation cohort.
### Table 1
Clinicopathologic Characteristics of the Training Cohort and Validation Cohort.

| Characteristics | Training Cohort (N = 251) | Validation Cohort (N = 81) |
|-----------------|----------------------------|-----------------------------|
|                 | N  | %  | OS (months) | N  | %  | OS (months) |
|                 | Median | 95% CI | Median | 95% CI |
| **Gender** |     |     |            |     |     |            |
| Male           | 155 | 61.8 | 15.5 | 11.8–22.1 | 50 | 61.7 | 14.0 | 11.0–15.2 |
| Female         | 96  | 38.2 | 16.1 | 11.5–23.9 | 31 | 38.3 | 10.1 | 7.9–16.0 |
| **Age** |     |     |            |     |     |            |
| < 60 year      | 134 | 53.4 | 23.9 | 16.6–29.6 | 47 | 58.0 | 14 | 11.0–18.6 |
| ≥ 60 year      | 117 | 46.6 | 10.4 | 7.99–13.6 | 34 | 42.0 | 9 | 8.0–14.0 |
| **BMI** |     |     |            |     |     |            |
| ≥ 18.5         | 186 | 74.1 | 16.67 | 13.47–23.9 | 74 | 91.4 | 12.6 | 11.0–15.0 |
| < 18.5         | 65  | 25.9 | 9.53 | 7.07–18.1 | 7  | 8.6 | 7.0 | 5.0–10.5 |
| **ALB** |     |     |            |     |     |            |
| < 35 g/L       | 68  | 27.1 | 7.5 | 4.63–13.5 | 16 | 19.7 | 10.2 | 5.0–11.4 |
| ≥ 35 g/L       | 183 | 72.9 | 20.2 | 15.6–26.0 | 65 | 80.3 | 12.0 | 10.1–15.2 |
| **CA19-9** |     |     |            |     |     |            |
| < 37 g/L       | 144 | 57.4 | 23.9 | 18.9–30.4 | 48 | 59.3 | 14.0 | 11.0–15.0 |
| ≥ 37 g/L       | 107 | 42.6 | 10.2 | 8.19–12.8 | 33 | 40.7 | 10.1 | 7.0–16.2 |
| **PCI** |     |     |            |     |     |            |
| < 16           | 157 | 62.5 | 23.87 | 17.9–27.90 | 13 | 16.0 | 15.2 | 9.0–20.4 |
| ≥ 16           | 94  | 37.5 | 7.39 | 5.7–9.35 | 68 | 84.0 | 11.0 | 10.0–14.0 |
| **CRS** |     |     |            |     |     |            |
| Characteristics          | Training Cohort (N = 251) | Validation Cohort (N = 81) |
|--------------------------|---------------------------|---------------------------|
|                          | N  | %   | OS (months)  | N  | %  | OS (months) |
| CC 0–1                   | 48 | 19.1| 35.2 | 20 | 24.7| 14.0 |
| CC 2–3 & NO             | 203| 80.9| 11.8 | 61 | 75.3| 10.5 |
| Hemoglobin              |    |     |      |    |     |      |
| < 100 g/L               | 75 | 29.8| 9.23 | 61 | 75.3| 10.5 |
| ≥ 100 g/L               | 176| 70.2| 20.57| 178| 24.7| 9.23 |
| CEA                     |    |     |      |    |     |      |
| < 5 ng/mL               | 87 | 34.7| 18.5 | 30 | 37.0| 11.0 |
| ≥ 5 ng/mL               | 164| 65.3| 13.0 | 51 | 63.0| 12.0 |
| CA125                   |    |     |      |    |     |      |
| < 35 U/ml               | 62 | 24.7| 25.2 | 47 | 58.0| 12.0 |
| ≥ 35 U/ml               | 189| 75.3| 13.0 | 34 | 42.0| 11.0 |
| LLM                     |    |     |      |    |     |      |
| No                      | 86 | 34.3| 14.9 | 25 | 30.9| 12.0 |
| Yes                     | 165| 65.7| 15.6 | 56 | 69.1| 10.2 |
| Location of primary tumor |   |     |      |    |     |      |
| Left-sided              | 145| 57.4| 16.7 | 34 | 42.0| 11.0 |
| Right-sided             | 106| 42.2| 13.6 | 47 | 58.0| 12.0 |
| Differentiation         |    |     |      |    |     |      |
| Good differentiated     | 121| 48.2| 17.9 | 19 | 23.5| 12.0 |
| Poor differentiated     | 130| 51.8| 12.8 | 62 | 76.5| 10.1 |
| HIPEC                   |    |     |      |    |     |      |
| Characteristics | Training Cohort (N = 251) | | Validation Cohort (N = 81) | |
|----------------|--------------------------|---|--------------------------|---|
|                | N | % | OS (months) | N | % | OS (months) | |
| Yes            | 46 | 18.3 | 16.7 | 10.6–30.2 | 18 | 22.2 | 14 | 11.0–19.0 |
| No             | 205 | 81.7 | 15.6 | 11.8–20.2 | 63 | 77.8 | 11 | 9.0–14.0 |

**Abbreviations**: ALB, albumin; PCI, peritoneal cancer index; CC, completeness of cytoreduction; HIPEC, hyperthermic intraperitoneal chemotherapy; LLM, Liver or lung metastasis.

In univariate analysis (Table 2), younger age (< 60 years old) or higher albumin (≥ 35 g/L) were associated with better prognosis (P < 0.001). PCI < 16 and complete CRS (CC 0–1) could predict favorable survival (P < 0.001). BMI (P = 0.016), tumor marker CA19-9 level (P < 0.001), CA125 level (P < 0.01) and hemoglobin level (P < 0.001) were also associated with survival. No survival associations were observed for other variables, including gender (P = 0.5), CEA (P = 0.2), liver or lung metastasis (P = 0.9), primary tumor location (P = 0.07), tumor pathology (P = 0.096), differentiation (P = 0.23) and HIPEC (P = 0.15). In multivariate analysis by Cox regression model, PCI (HR = 1.986, 95% CI 1.411–2.795, P < 0.001), complete CRS (HR = 0.512, 95% CI 0.311–0.843, P < 0.01), age (HR = 1.667, 95% CI 1.210–2.298, P < 0.01), albumin (HR = 0.653, 95% CI 0.564–0.917, P = 0.014) and CA19-9 (HR = 1.436, 95% CI 1.034–1.994, P = 0.039) were independent prognostic factors of survival (Table 2). All variables were analyzed for potential inclusion in the final multivariable models by forward regression. However, variables with no significance and clinically relevant interactions were identified for either end point, where clinical relevance was checked via examination of spline plots for continuous variables and hazard ratios for categorical variables across subgroups (data not shown).
| Variables                  | Univariate Analysis (P value) | Multivariable Analysis | Variables in the nomogram |
|----------------------------|-------------------------------|------------------------|---------------------------|
|                            |                               | HR 95% CI              | P value                   | HR 95% CI              | P value   |
| Gender                     | 0.5                           |                        |                           |                        |           |
| Male                       | Refer                         | 0.542–1.127            | 0.19                      | Refer                  |           |
| Female                     | 0.782                         |                        |                           |                        |           |
| Age                        | <0.001                        |                        |                           |                        |           |
| < 60 year                  | Refer                         | 1.236–2.484            | <0.001                    | Refer                  | 1.210–2.298 | <0.01     |
| ≥ 60 year                  | 1.768                         |                        |                           |                        |           |
| BMI                        | 0.02                          |                        |                           |                        |           |
| < 18.5                     | Refer                         | 0.515–1.055            | 0.09                      | Refer                  | 0.465–0.917 | 0.014     |
| ≥ 18.5                     | 0.737                         |                        |                           |                        |           |
| ALB                        | <0.001                        |                        |                           |                        |           |
| < 35 g/L                   | Refer                         | 0.494–1.00             | <0.05                     | Refer                  | 1.034–1.994 | 0.031     |
| ≥ 35 g/L                   | 0.703                         |                        |                           |                        |           |
| CA19-9                     | <0.001                        |                        |                           |                        |           |
| < 37 g/L                   | Refer                         | 1.103–2.227            | <0.05                     | Refer                  | 1.411–2.795 | <0.001    |
| ≥ 37 g/L                   | 1.567                         |                        |                           |                        |           |
| PCI                        | <0.001                        |                        |                           |                        |           |
| < 16                       | Refer                         | 1.294–2.680            | <0.001                    | Refer                  | 1.411–2.795 | <0.001    |
| ≥ 16                       | 1.862                         |                        |                           |                        |           |
| CRS                        | <0.001                        |                        |                           |                        |           |
| CC 2–3 & NO                | Refer                         | 0.349–0.969            | <0.05                     | Refer                  | 0.311–0.843 | <0.01     |
| CC 0–1                     | 0.581                         |                        |                           |                        |           |
| Hemoglobin                 | <0.001                        |                        |                           |                        |           |
| < 100 g/L                  | Refer                         | 0.557–1.127            | 0.16                      |                        |           |
| ≥ 100 g/L                  | 0.793                         |                        |                           |                        |           |
| CEA                        | 0.2                           |                        |                           |                        |           |
| Variables                        | Univariate Analysis (P value) | Multivariable Analysis | Variables in the nomogram |
|---------------------------------|------------------------------|------------------------|---------------------------|
|                                 |                              | HR         | 95% CI       | P value | HR         | 95% CI       | P value |
| < 5 ng/mL                       | Refer                        | 0.643–1.298 | 0.64   |         |         |         |        |
| ≥ 5 ng/mL                       |                              | 0.913      |         |         |         |         |        |
| CA125                           | 0.006                         |            |        |         |         |         |        |
| < 35 U/ml                       | Refer                        | 0.764–1.866 | 0.4362 |         |         |         |        |
| ≥ 35 U/ml                       |                              | 1.194      |         |         |         |         |        |
| LLM                             | 0.9                           |            |        |         |         |         |        |
| Yes                             | Refer                        | 0.773–1.508 | 0.68   |         |         |         |        |
| No                              |                              | 1.080      |         |         |         |         |        |
| Location of primary tumor       | 0.07                          |            |        |         |         |         |        |
| Left-sided                      | Refer                        | 0.777–1.479 | 0.66   |         |         |         |        |
| Right-sided                     |                              | 1.072      |         |         |         |         |        |
| Differentiation                 | 0.4                           |            |        |         |         |         |        |
| Good differentiated             | Refer                        | 0.791–1.514 | 0.61   |         |         |         |        |
| Poor differentiated             |                              | 1.094      |         |         |         |         |        |
| HIPEC                           | 0.2                           |            |        |         |         |         |        |
| Yes                             | Refer                        | 0.446–1.048 | 0.09   |         |         |         |        |
| No                              |                              | 0.683      |         |         |         |         |        |

**Abbreviations:** ALB, albumin; PCI, peritoneal cancer index; HR, hazard ratio; HIPEC, hyperthermic intraperitoneal chemotherapy; LLM, Liver or lung metastasis; Refer, reference.

A model by incorporating these independent prognostic factors was constructed and shown as a nomogram (Fig. 1). Each variable at the topic line located on the relevant axis. A straight line is drawn up to the point axis. Each variable was scored and the final score of individuals was the sum of all variables, which was matched to the survival rate of 0.5-, 1-, 2-, and 3-year for individual patient.

In the training cohort, the C-index of nomogram was 0.713 (95% CI, 0.674–0.752). The AUC by the time-dependent ROC curve of 0.5-, 1-, 2-, and 3-years were 0.753, 0.781, 0.774 and 0.741, respectively (Fig. 2). All of these shown a good discrimination of the nomogram. The calibration curves of 0.5-, 1-, 2- and 3-years OS in the validation cohort were shown in Fig. 3. These results indicated the predicted OS of nomogram had a good correlation with the actual OS. In addition, the Hosmer-Lemeshow test was not
statistically significant \((P = 0.881)\), which suggested the good fitting of the nomogram. In validation cohort, the model displayed good discrimination with a C-index of 0.642 (95\% CI: 0.563–0.720). A non-statistical significance was also observed in the Hosmer–Lemeshow test \((P = 0.317)\). The nomogram was validated by calibration curves of 0.5-, 1-, 2- and 3-years OS with good correlations with actual OS (Fig. 4).

**Discussion**

In this study, we have constructed a nomogram and validated it with satisfied performances in a validation cohort of PM patients. This nomogram can individually predict 0.5-,1-,2- and 3-year OS of PM patients. As the prognosis of synchronous peritoneal metastasis of colorectal cancer is extremely poor, and the median survival time of its natural outcome is about 0.5 years. The 3-year survival rate is very low after CRS plus HIPEC treatment. Therefore, we have adopted multiple survival time within three years, which is more precise and more suitable in clinical practice. By incorporating demographic and clinical characteristics, the nomogram showed good discrimination and calibration performance by C-index and calibration curve, and is an easy-to-use noninvasive tool for clinicians to estimate the OS and personalize subsequent treatments for individuals. More efficient chemotherapy regime is needed for PM patients with low probability of survival.

PM often is considered to be the terminal state, and obtains worst survival, comparing to other organ metastases. However, the median survival of CRS plus systemic chemotherapy can reach 16 months, which was consistent with the survival of 15.6 months in this study. PCI, CRS and CA19-9 are related to the prognosis of PM patients both in our study and previous studies\(^{23–25}\). CA19-9 is one important predictor of disease recurrence and associated with postoperative peritoneal recurrence\(^{26}\). In our nomogram, PCI score and CRS act the important roles in the model, especially PCI score. PCI score can be obtained by radiological examination and surgical evaluation. The sensitivity of CT scan in diagnosis of PM nodules < 5 mm is only 11–48\%. The limited sensitivity of CT scans can influence the diagnosis of PM, the diagnostic power of PM can be improved with the development of artificial intelligence to assist the imaging diagnosis\(^{27}\). Therefore, radiological PCI is less sensitive than surgical PCI\(^{28–29}\). In PM with PCI score > 17, CRS + HIPEC does not offer additional survival benefit\(^{30}\). CRS can resolute bowel obstruction and remit bleeding to improve quality of life and create good physical condition to receive systematic chemotherapy and prolong the OS as possible\(^{31–32}\). The survival benefit can exceed the disadvantage of high risks of surgical complications for CRS.

It is generally believed that the prognosis of multiple organ metastasis will be worse than single organ metastasis. However, one study suggested that colorectal cancer with liver/lung metastasis obtained similar survival to those with peritoneal-only involvement\(^{33}\). We thought the survival of synchronous peritoneal metastasis is extremely poor than multiple organ metastasis including liver/lung metastasis, which can survive for more than 2 years in many patients. Therefore, the presence of liver/lung
metastasis may not be a separate factor affecting the prognosis for synchronous peritoneal metastasis of colorectal cancer patients.

Sugarbaker firstly proposed CRS procedure in PM and reported the median operation time was 8 h (5–10 h) with 3.9L (0.5-30L) of blood loss during operation. The overall morbidity rate varied from 23 to 44%, and the mortality rate ranged from 0 to 12% in nine different institutions. The delayed complications that may result from extensive CRS included both anatomic (bowel obstruction, perforation, and hemorrhage) and functional symptoms (short bowel syndrome, and uncontrolled diarrhea). The PRODIGE 7 study which compares CRS with or without HIPEC in PM shows that the incidence of surgical complications above grade 3 was 13.6%-24.1%. Therefore, CRS was not suitable for every patient, and even fewer patients have achieved CC 0–1. In this study, only 68 patients (20.4%) obtain the opportunity to receive CRS and achieve CC 0–1.

Several prognostic scores have been developed to predict the OS of PM patients in CRC. PSDSS and COMPASS are the most commonly applied. However, overall survival was analyzed according to five tiers of estimated disease severity in PSDSS. The calculation of the PSDSS is not based on the regression coefficient of a Cox proportional hazard model, it cannot predict the individualized survival rate of patients. The COMPASS included age, regional lymph node status, PCI and pathological features. It can guide clinicians to predict the OS after operating CRS plus HIPEC in different stages of PM. In addition, a study shown that the prediction effect of COMPASS is better than that of the PSDSS model. The C-index of the training cohort of the COMPASS model was 0.72( 95%CI, 0.66–0.78), which was similar to the model in our study(0.713, 95%CI 0.674–0.752). When we took the training cohort of our model to be an external validation cohort of the COMPASS. The C-index of the external validation cohort was 0.681(95% CI, 0.64–0.72), that the result indicated a comparable database between the two cohorts. Both PSDSS and COMPASS cannot predict the prognosis of patients who do not have the opportunity to surgery. The variables in the nomogram of this study can be easily obtained at the initial diagnosis in clinic for patient selection. It is also applicable to some patients who have not been able to obtain pathological tissue types and lymph node infiltration results. We believe that this model is an innovative and practical tool for clinicians to provide patients with predicted individualized survival and guide the surveillance.

There are some limitations in this study. Firstly, this study was a retrospective analysis, potential selection and recall bias may exist. Secondly, the PCI in this model are obtained during surgery and was classified at 16, detailed PCI scores are needed for each patient in future study to establish better association with survival. Lastly, the sample size of PM patients in the nomogram is limited and only Asian population are included. Larger sample size and population from other areas are needed in future work. The accuracy of this nomogram model could be further improved.

Conclusion
In summary, we had developed an easy-to-use non-invasive model to predict overall survival of synchronous PM in CRC. The main objective of this predictive model is achieved with the methodology exposed, and the model will help to predict the prognosis of synchronous PM of CRC, but also can give information for the treatment decision.

**Abbreviations**

| PM   | peritoneal metastases                  |
|------|----------------------------------------|
| OS   | overall survival                       |
| PCI  | peritoneal cancer index                |
| CRS  | cytoreductive surgery                  |
| CRC  | Colorectal cancer                      |
| HIPEC| hyperthermic intraperitoneal chemotherapy |
| NCCN | National Comprehensive Cancer Network  |
| PSDSS| Peritoneal Surface Disease Severity Score |
| COMPASS | Colorectal Peritoneal Metastases Prognostic Surgical Score |
| BMI  | body mass index                        |
| CC   | completeness of cytoreductive surgery  |
| C-index | concordance index                    |
| ALB  | albumin                                |
| HR   | hazard ratio                           |
| LLM  | Liver or lung metastasis               |

**Declarations**

**Ethics approval and consent to participate**

The study was approved by the local Ethics Committee of The Sixth Hospital affiliated of Sun Yat-Sen University (No. 2020ZSLYEC-107).

**Consent for publication**

Not applicable
Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Study design: JC, HW; Development of methodology: YH, WLC, ZXY, AWW; Acquisition of data, analysis and interpretation of data (e.g., statistical analysis, biostatistics, computational analysis): ZYY, QXL, HMW,YL,QSD, DL,MHW; Writing, review and/or revision of the manuscript: WLC, ZXY, AWW; Study supervision: JC, HW, YH; Revising: JC, HW; All of the authors reviewed and approved the final manuscript.

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Figures
Figure 1

Postoperative prognostic nomogram for patients with synchronous colorectal peritoneal metastasis. Abbreviations: ALB, albumin; PCI, peritoneal cancer index; CC, completeness of cytoreduction.
Figure 2

Time-independent Receiver operating characteristic (ROC) curve for evaluating the model's discrimination performance in at each time point. Fig. 2 Time-independent Receiver operating characteristic (ROC) curve for evaluating the model's discrimination performance in at each time point. The AUCs of ROC curve to assess discrimination performance were listed in 0.5-year (0.753) (A), 1-year (0.781) (B), 2-year (0.774) (C), 3-year (0.741) (D).
Figure 3

The calibration curves of training cohort for predicting patient survival. A) in 0.5-year; B) in 1-year; C) in 2-year; D) in 3-year. Nomogram-predicted overall survival (OS) is plotted on the x-axis; actual OS is plotted on the y-axis. A plot along the 45-degree line would indicate a perfect calibration model in which the predicted probabilities are identical to the actual outcomes. In a perfectly calibrated model, predictive rates (red line) would fall on a 45-degree diagonal line (gray line).
Figure 4

The calibration curves of validation cohort for predicting patient survival. A) in 0.5-year; B) in 1-year; C) in 2-year; D) in 3-year. Nomogram-predicted overall survival (OS) is plotted on the x-axis; actual OS is plotted on the y-axis. A plot along the 45-degree line would indicate a perfect calibration model in which the predicted probabilities are identical to the actual outcomes. In a perfectly calibrated model, predictive rates (red line) would fall on a 45-degree diagonal line (gray line).