Radiomics signature for predicting postoperative disease-free survival of patients with gastric cancer: development and validation of a predictive nomogram

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PURPOSE
Radiomics can be used to determine the prognosis of gastric cancer (GC). The objective of this study was to predict the disease-free survival (DFS) after GC surgery based on computed tomography-enhanced images combined with clinical features.

METHODS
Clinical, imaging, and pathological data of patients who underwent gastric adenocarcinoma resection from June 2015 to May 2019 were retrospectively analyzed. The primary outcome was DFS. Radiomics features were selected using Least Absolute Shrinkage and Selection Operator algorithm and converted into the Rad-score. A nomogram was constructed based on the Rad-score and other clinical factors. The Rad-score and nomogram were validated in the training and validation groups.

RESULTS
Totally, 179 patients were randomly divided into the training (n = 124) and validation (n = 55) groups. In the training group, validation group, and overall population, the Rad-score could be divided into categories indicating low, moderate, and high risk of recurrence, metastasis, or death; all risk categories showed a significant difference between the training, validation, and overall population groups (all P < .001). Positive lymph nodes (hazard ratio (HR) = 3.07, 95% CI: 1.52-6.23, P = .002), cancer antigen-125 (HR = 3.24, 95% CI: 1.54-6.80, P = .002), and the Rad-score (HR = 0.73, 95% CI: 0.61-0.87, P < .001) were independently associated with DFS. These 3 variables were used to construct a nomogram. In the training group, the areas under the curve at 3 years were 0.758 and 0.776 for the Rad-score and the nomogram, respectively, while they were both 1.000 in the validation group. The net benefit rate was analyzed using a decision curve in the training and validation groups, and the nomogram was superior to the single Rad-score.

CONCLUSION
Rad-score is an independent factor for DFS after gastrectomy for GC. The nomogram established in this study could be an effective tool for the clinical prediction of DFS after gastrectomy.

Gastric adenocarcinomas are the most common type of stomach cancer.1,2 There are 1 033 701 new gastric cancer (GC) cases and 872 685 GC-related deaths worldwide in 2018.3 Some regions including Eastern Asia, Eastern Europe, and South America have the highest incidence of GC.4,5 The treatment management of GC includes surgery, chemotherapy, radiation therapy, and targeted therapy.1,4,5 The 5-year survival of GC patients with localized, regional, and distant-stage diseases are 67%, 31%, and 5%, respectively.1,4,5 The classical prognostic factors for GC include tumor size, lymphovascular invasion, nodal involvement, positive peritoneal cytology, signet ring cell adenocarcinoma,1,2,4 age, sex,6 and obesity.7,8 TNM (T: primary tumor, N: lymph node, M: distant metastasis) staging system and histopathological classification have been widely used as the prognostic tools for GC, which can help to formulate the treatment strategy.1,4,5 However, their predictive ability remains limited.9-11 Novel prognostic biomarkers are also being explored, with similar restrictions.12-14 In recent years, several functional imaging methods such as computed tomography (CT) perfusion, diffusion-weighted imaging (DWI), and dynamic contrast-enhanced magnetic resonance imaging have been developed. The stomach is a hollow
moving organ filled with liquid and gas, and its motion may exacerbate artifacts, resulting in image distortion and ghosting. In addition, concerning the DWI sequence, susceptibility artifacts, distortions, and blurring are inevitable due to the slow traversal through the k-space line and the narrow bandwidth along the phase encoding direction. Among them, emerging radiomics is a promising prognostic tool for GC. Radiomics signatures, which compose of a series of CT texture features, are considered to be a stronger predictive factor, providing additional information beyond the traditional clinical factors.

Previous studies examined the predictive value of radiomics in GC prognosis. A study showed that radiomics could predict recurrence-free survival (RFS) in locally advanced GC. Another radiomics-based model could predict lymphovascular invasion and progression-free survival (PFS) but not overall survival (OS). However, GC radiomics is still in its infancy, facing multiple challenges.

Therefore, this study aimed to predict the disease-free survival (DFS) after GC surgery based on preoperative CT-enhanced images combined with clinical features. The results may help to improve the ability to predict DFS after gastrectomy.

### Methods

#### Study design and patient data

This retrospective study analyzed the clinical, imaging, and pathological data of patients who underwent gastric adenocarcinoma resection from June 2015 to May 2019. The study was approved by the Ethics Committee. The decision number of Ethics Committee approval is LW-20220210001-01.

All patients were pathologically diagnosed with gastric adenocarcinoma according to the 2010 World Health Organization (WHO) Classification of Tumours of the Digestive System. The inclusion criteria

| Table 1. Characteristics of the patients |
|------------------------|-------------------|------------------|----------------|---|
| General characteristics | Total (n = 179) | Training (n = 124) | Validation (n = 55) | P |
| Age (year) | | | | .062 |
| ≤60 years | 67 (37.4%) | 38 (30.6%) | 29 (52.7%) | |
| >60 years | 112 (62.6%) | 86 (69.4%) | 26 (47.3%) | |
| Sex | | | | .961 |
| Male | 129 (72.1%) | 90 (72.6%) | 39 (70.9%) | |
| Female | 50 (27.9%) | 34 (27.4%) | 16 (29.1%) | |
| CEA | | | | .765 |
| ≤5 ng/mL | 145 (81.0%) | 107 (86.3%) | 38 (69.1%) | |
| >5 ng/mL | 34 (19.0%) | 17 (13.7%) | 17 (30.1%) | |
| CA-125 | | | | .359 |
| ≤35 U/mL | 156 (87.2%) | 107 (86.3%) | 49 (89.1%) | |
| >35 U/mL | 23 (12.8%) | 17 (13.7%) | 6 (10.9%) | |
| CA-199 | | | | .537 |
| ≤27 U/mL | 133 (74.3%) | 93 (75.0%) | 40 (72.7%) | |
| >27 U/mL | 46 (25.7%) | 31 (25.0%) | 15 (27.3%) | |
| CA-153 | | | | .764 |
| ≤25 U/mL | 164 (91.6%) | 112 (90.3%) | 52 (94.5%) | |
| >25 U/mL | 15 (8.4%) | 12 (9.7%) | 3 (5.5%) | |
| NSE | | | | .712 |
| ≤16 ng/mL | 163 (91.1%) | 111 (89.5%) | 52 (94.5%) | |
| >16 ng/mL | 16 (8.9%) | 13 (10.5%) | 3 (5.5%) | |
| Maximal diameter of the tumor | | | | .538 |
| ≤30 mm | 41 (22.9%) | 30 (24.2%) | 11 (20.0%) | |
| >30 mm | 138 (77.1%) | 94 (75.8%) | 44 (80.0%) | |
| Thickness of the tumor | | | | .772 |
| ≤20 mm | 98 (54.7%) | 67 (54.0%) | 31 (56.4%) | |
| >20 mm | 81 (45.3%) | 57 (46.0%) | 24 (43.6%) | |
| Internal necrosis | | | | .9 |
| 172 (96.1%) | 119 (96.0%) | 53 (96.4%) | |
| Borrmann classification | | | | .627 |
| Type I | 0 | 0 | 0 | |
| Type II | 19 (10.6%) | 15 (12.1%) | 4 (7.3%) | |
| Type III | 72 (40.2%) | 49 (39.5%) | 23 (41.8%) | |
| Type IV | 88 (49.2%) | 60 (48.4%) | 28 (50.9%) | |
| Tumor location | | | | .578 |
| Cardia | 44 (24.6%) | 33 (26.6%) | 11 (20%) | |
| Body | 23 (12.8%) | 17 (13.7%) | 6 (10.9%) | |
| Antrum | 83 (46.4%) | 56 (45.2%) | 27 (49.1%) | |
| Whole | 29 (16.2%) | 18 (14.5%) | 11 (20%) | |
| ct staging | | | | .905 |
| cT1 | 1 (0.6%) | 1 (0.8%) | 0 | |
| cT2 | 22 (12.3%) | 15 (12.1%) | 7 (12.7%) | |
| cT3 | 62 (34.6%) | 42 (33.9%) | 20 (36.4%) | |
| cT4 | 94 (52.5%) | 66 (53.2%) | 28 (50.9%) | |

(Continued)
were (1) diagnosis of gastric adenocarcinoma by pathological examination, (2) complete clinical, imaging, and pathological data, (3) no anti-tumor treatment before CT examination, and (4) radical GC surgery within 2 weeks after CT examination. The exclusion criteria were (1) poor image quality, (2) the lesion being too small to delineate the region of interest (ROI), or (3) follow-up lesion being too small to delineate the region of interest (ROI).

Follow-up

GC patients were followed up routinely every 3 months during the first 2 years after surgery and every 6 months thereafter. Follow-up was censored on May 30, 2019. Routine follow-up included laboratory examinations (carcinoembryonic antigen (CEA), cancer antigen (CA)-125, CA-199, etc.) and imaging examinations (CT plain and enhanced scans), positron emission tomography-CT, and magnetic resonance imaging if deemed necessary.

The primary outcome was DFS. DFS was defined as the period from the first postoperative day to tumor recurrence, diagnosis of metastasis, or all-cause death, whichever occurred first.

Observational indicators

Clinical factors that might be related to DFS included sex, age, pathological diagnosis, histological differentiation, depth of invasion, number of metastatic lymph nodes, tumor markers (CEA, CA-125, CA-199, CA-153, and neuron-specific enolase), and immunohistochemistry staining results for CD34, vascular endothelial growth factor, epidermal growth factor receptor, and Human epidermal growth factor receptor-2 (HER-2) (0 = negative, 1 = weakly positive, and 2 = strongly positive), Ki-67 index, and adjuvant treatment. Histological differentiation was classified into well-differentiated, moderately moderately differentiated, moderately poorly differentiated, and poorly differentiated. The postoperative pathological staging was determined according to the standards stated in the eighth edition of American Joint Committee on Cancer.

There were several forms of adjuvant treatment. We considered these adjuvant treatments had effects on DFS, so we considered the adjuvant treatment as one variable.

The basic imaging features that might be related to DFS included tumor size (maximum diameter of the largest cross-section, mm), internal tumor necrosis, tumor thickness (thickness of the largest cross-section, mm) Borrmann classification of tumor types (type I-protruding type, type II-superficial ulcerative type, III-ulcer-infiltrating type, and type IV-diffuse infiltrative type), preoperative primary tumor staging (cT staging), and preoperative lymph node staging (cN staging). Two attending radiologists who, respectively, had 10 and 6 years of experience in abdominal imaging diagnosis and were unaware of the contents of the study evaluated the basic imaging characteristics of the included patients. When the assessment results were inconsistent, a chief radiologist with 20 years of experience in abdominal CT diagnosis made the final decision.

CT examination

Food and water were prohibited for 12 hours. Ten minutes before the examination, 15 mg of anisodamine was injected intramuscularly to reduce gastric motility, and 1200 mL of water was drunk to expand the gastric cavity. During the examination, after a plain scan in the supine position, 80 mL of radiocontrast agent (Ultravist 370, Bayer) was injected through the median cubital vein at 3.0 mL/s (High-Pressure Injector, CT Plus 150, Ulrich Medical). The

Table 1. Characteristics of the patients (Continued)

| General characteristics | Total (n = 179) | Training (n = 124) | Validation (n = 55) | P |
|-------------------------|----------------|-------------------|--------------------|---|
| cN staging              |                |                   |                    | .743 |
| Negative                | 65 (36.3%)     | 46 (37.1%)        | 19 (34.5%)         |    |
| Positive                | 114 (63.7%)    | 78 (62.9%)        | 36 (65.5%)         |    |
| pT staging              |                |                   |                    | .988 |
| T1                      | 5 (2.8%)       | 4 (3.2%)          | 1 (1.8%)           |    |
| T2                      | 23 (12.8%)     | 17 (13.7%)        | 6 (10.9%)          |    |
| T3                      | 66 (36.9%)     | 46 (37.1%)        | 20 (36.4%)         |    |
| T4                      | 85 (47.5%)     | 57 (46.0%)        | 28 (50.9%)         |    |
| Differentiation degree  |                |                   |                    | .667 |
| Poor                    | 113 (63.1%)    | 79 (63.7%)        | 34 (61.8%)         |    |
| Moderate                | 53 (29.6%)     | 35 (28.2%)        | 18 (32.7%)         |    |
| Well-differentiated     | 13 (7.3%)      | 10 (8.1%)         | 3 (5.5%)           |    |
| Lymph node metastasis   | 115 (64.2%)    | 77 (62.1%)        | 38 (69.1%)         | .98 |
| CD34-positive           | 136 (76.0%)    | 91 (73.4%)        | 45 (81.8%)         | .141 |
| HER-2-positive          | 87 (48.6%)     | 62 (50.0%)        | 25 (45.5%)         | .368 |
| VEGF                    |                |                   |                    | .771 |
| Negative                | 23 (12.8%)     | 16 (12.9%)        | 7 (12.7%)          |    |
| Weakly positive         | 48 (26.8%)     | 34 (27.4%)        | 14 (25.5%)         |    |
| Strongly positive       | 108 (60.3%)    | 74 (59.7%)        | 34 (61.8%)         |    |
| EGFR                    |                |                   |                    | .485 |
| Negative                | 26 (14.5%)     | 18 (14.5%)        | 8 (14.5%)          |    |
| Weakly positive         | 66 (36.9%)     | 40 (32.3%)        | 26 (47.3%)         |    |
| Strongly positive       | 87 (48.6%)     | 66 (53.2%)        | 21 (38.2%)         |    |
| Ki-67 index             |                |                   |                    | .918 |
| ≤50%                    | 52 (29.1%)     | 35 (28.2%)        | 17 (30.9%)         |    |
| >50%                    | 127 (70.9%)    | 89 (71.8%)        | 38 (69.1%)         |    |
| Adjuvant treatment      | 116 (64.8%)    | 81 (65.3%)        | 35 (63.6%)         | .532 |
| Recurrence, metastasis, or all-cause death | 84 (46.9%) | 58 (46.8%) | 26 (47.3%) | .465 |

CEA, carcinoembryonic antigen; CA, cancer antigen; NSE, neuron-specific enolase; VEGF, vascular endothelial growth factor; EGFR, epithelial growth factor receptor.
The CT machine with a 64 LightSpeed VCT (GE Healthcare) or SOMATOM Definition Dual Source CT (Siemens) was adopted. Extraction of textural features

The image data of the arterial and portal venous phases with reconstructed layer thicknesses of 5 and 1.25 mm were exported. A radiologist with 6 years of experience used the open-source software 3D Slicer (http://www.slicer.org Version:4.10.2) to draw an ROI on the stomach lesion in which the largest layer was selected, paying attention to exclude adjacent gas and fat. The gray value in the ROI was analyzed using the radiomics plug-in in 3D Slicer. Radiologist A had 6 years of experience in abdominal CT diagnosis and 2 years of experience in textural feature extraction, and radiologist B had 10 years of experience in abdominal

Figure 1. a, b. LASSO regression model for screening the radiomics characteristics of the training group. (a) The vertical axis represents the coefficients corresponding to 776 radiomics characteristics, and the horizontal axis represents log $\lambda$. (b) The vertical axis represents the corresponding AUC, and the horizontal axis represents log $\lambda$. In the LASSO program, $n_\lambda = 100$, $n_{folds} = 10$, and the minimum multiple of 1 standard deviation is used. LASSO, Least Absolute Shrinkage and Selection Operator algorithm; AUC, area under the curve.

Figure 2. a-c. Comparison between the Rad-score of recurrence/metastasis and the Rad-score of no recurrence/metastasis of the training group (a), the validation group (b), and the overall study population (c). Red indicates that the patient has recurrence/metastasis. Blue indicates the patient has no recurrence/metastasis. The vertical axis indicates the Radiomics score (RS) score.
CT diagnosis and 1 year of experience in textural feature extraction. They randomly selected the venous phase imaging data of 30 cases, with a layer thickness of 1.25 mm, and performed lesion ROI delineation and textural feature extraction independently without knowing the research content and clinical data. Radiologist A performed feature extraction again on the same image 1 month later to evaluate its repeatability and then completed feature extraction of other image data.

Surgical procedure

The surgical procedures for GC included Billroth I and II gastrojejunostomy, Roux-en-Y hepaticojejunostomy, and others, as listed in Table 5.

Statistical analysis

In the training group, Least Absolute Shrinkage and Selection Operator (LASSO) algorithm was used in dimensionality reduction of the features to select the textural features that could predict the DFS. The selected minimum textural feature value was multiplied by the corresponding coefficient to obtain the radiomics score (Rad-score). According to the case status (recurrence, metastasis, or death) and DFS time, the X-tile software was used to calculate the cutoff value of the Rad-score. The relationship between the Rad-score and DFS was evaluated through Kaplan–Meier survival analysis. The patients were divided into the high-, moderate-, and low-risk groups based on the Rad-score value.

In the training group, univariable analysis was performed on the included clinical features (categorical variables) using the Cox survival analysis. Variables with $P < .05$ were included in the Cox multivariable analysis (forward stepwise). Variables left in the final equation were used to establish a predictive nomogram. The time-dependent receiver operating characteristics (ROC) curves and decision curves were drawn to evaluate the predictive ability of the nomogram.

Categorical data were presented as n (%) and analyzed using the chi-square test or Fisher exact test. The statistical software used included R 3.0.1, X-tile 3.6.1 (https://medicine.yale.edu/lab/rimm/research/software), and Statistical Package for the Social Sciences software 26.0 (IBM). A two-sided $P$-value < .05 was considered statistically significant.

Results

From June 2015 to May 2019, 654 patients underwent gastric adenocarcinoma resection. Among them, 179 patients met the eligibility criteria and were randomly divided into the training (n = 124) and validation (n = 55) groups. There were no statistically significant differences between the 2 groups (Table 1).

In the training group, 7 features with a non-zero coefficient were selected through the LASSO regression model, as shown in Figure 1. Based on these 7 features, the Rad-score was constructed as the following equation:

\[
\text{Rad-score} = 11.581 - 0.009 \times \text{original}_\text{shape}_\text{Maximum 2D Diameter Column} - 0.252 \times \text{original}_\text{glrlm}_\text{Run Entropy} + 0.002 \times \text{original}_\text{glrlm}_\text{Run Length NonUniformity Normalized} - 0.257 \times \text{square}_\text{firstorder}_\text{Skewness} - 0.805 \times \text{wavelet-HLH_glszm_Zone Entropy} - 11.540 \times \text{wavelet-HHL_glcm_Sum Squares} + 1.067 \times \text{wavelet-HHL_glmRun Length NonUniformity Normalized}.
\]

Figure 3. a-f. (a-b) Use of X-tile to predict the best Rad-score value of DFS in the training group (n = 124). (c-d) Use of X-tile to predict the best Rad-score value of DFS in the validation group (n = 55). (e-f) Use of X-tile to predict the best Rad-score value of DFS of all cases (n = 179). Pink means cases with low risk of recurrence/metastasis/death, blue means cases with high risk of recurrence/metastasis/death, and grey means cases with moderate risk of recurrence/metastasis/death. DFS, disease-free survival.
recurrence, metastasis, or death (Figure 3 and Supplementary Tables S1-S3). The Rad-scores in all risk categories were significantly different (all $P < .001$) between the training, validation, and overall population groups.

Table 2 shows that the Rad-score ($P < .001$), CA-125 ($P = .010$), maximal diameter of the tumor ($P = .018$), thickness of the tumor ($P = .002$), Borrmann classification ($P = .008$), cT staging ($P = .001$), cN staging ($P = .007$), pT staging ($P = .006$), differentiation degree ($P = .026$), positive lymph nodes ($P = .002$), and positive-CD34 ($P = .043$) are associated with DFS in the univariable analysis. Multivariable analysis showed that positive lymph nodes (hazard ratio (HR) = 3.07, 95% CI: 1.52-6.23, $P = .002$), CA-125 (HR = 3.24, 95% CI: 1.54-6.80, $P = .002$), and Rad-score (HR = 0.73, 95% CI: 0.61-0.87, $P < 0.001$) were independently associated with DFS (Table 3).

In the training group, a nomogram based on 2 clinical variables and the Rad-score was constructed, as shown in Figure 4. The time-dependent ROC curve verification was performed in the training and validation groups. In the training group, the areas under the curve (AUCs) at 3 years were 0.758 and 0.776 for the Rad-score and the nomogram, respectively, while they were both 1.000 in the validation group (Figure 5 and Table 4).

The net benefit rate was analyzed using a decision curve in the training and validation groups. Compared with the Rad-score alone, the net benefit of the nomogram showed better predictive ability (Figure 6).

ROC curve analysis was performed to assess the predictive capability of the Rad-score, clinical model (incorporating lymphadenopathy and CA-125), and the combined model of the training group. The

| Table 2. Univariable analysis of DFS in the training group |
|-----------------|-----------------|--------|
| Variables       | HR (95% CI)     | $P$    |
| Rad-score       | 0.700 (0.588-0.833) | <.001  |
| Age             | 1.039 (0.598-1.804) | .893   |
| Sex             | 0.935 (0.519-1.684) | .823   |
| CEA             | 0.828 (0.392-1.751) | .621   |
| CA-125          | 0.389 (0.189-0.800) | .010   |
| CA-199          | 1.770 (0.915-3.422) | .090   |
| CA-153          | 1.658 (0.783-3.512) | .187   |
| NSE             | 0.663 (0.240-1.834) | .429   |
| Maximal diameter of the tumor | 2.461 (1.165-5.201) | .018 |
| Thickness of the tumor | 2.353 (1.383-4.001) | .002 |
| Internal necrosis | 3.151 (0.436-22.784) | .255 |
| Borrmann classification | 1.750 (1.159-2.641) | .008 |
| cT staging | 2.060 (1.340-3.166) | .001 |
| cN staging | 2.298 (1.258-4.200) | .007 |
| pT staging | 1.678 (1.163-2.420) | .006 |
| Differentiation degree | 0.581 (0.360-0.936) | .026 |
| Lymphatic metastasis | 2.653 (1.427-4.931) | .002 |
| CD34 | 2.084 (1.023-4.244) | .043 |
| HER-2 | 1.489 (0.884-2.508) | .135 |
| VEGF | 1.073 (0.749-1.536) | .702 |
| EGFR | 1.283 (0.892-1.845) | .179 |
| Ki-67 Index | 1.076 (0.604-1.916) | .803 |
| Adjuvant treatment | 1.462 (1.109-3.471) | .179 |

HR, hazard ratio; CEA, carcinoembryonic antigen; CA, cancer antigen; NSE, neuron-specific enolase; VEGF, vascular endothelial growth factor; EGFR, epithelial growth factor receptor.

| Table 3. Multivariable analysis of the risk factors affecting DFS in the training group |
|-----------------|-----------------|--------|
| Risk factor     | HR (95% CI)     | $P$    |
| Lymphatic metastasis | 3.074 (1.518-6.227) | .002 |
| CA-125          | 3.239 (1.542-6.804) | .002 |
| Rad-score       | 0.726 (0.605-0.872) | <.001 |
| HR, hazard ratio; CA, cancer antigen.

| Figure 5. a-d. (a) Time-dependent receiver operating characteristic curves of the Rad-score in the training group. (b) Time-dependent ROC curves of Rad-score in the validation group. (c) Time-dependent ROC curves of nomogram in the training group. (d) Time-dependent ROC curves of nomogram in the validation group. ROC, receiver operating characteristic.
to predict DFS after GC surgery based on CT-enhanced images combined with clinical features. The results suggested that the Rad-score was an independent predictive factor for DFS after gastrectomy. The nomogram could be an effective tool for the clinical prediction of DFS after gastrectomy.

Radiomics has been explored for the differential diagnosis of GC and the prediction of its histological grade, tumor stage, response to therapy, and prognosis. Shin et al. showed that radiomics could predict RFS in patients with locally advanced GC. Chen et al. developed a radiomics-based model that could predict lymphovascular invasion and PFS but not OS. In postoperative patients, Giganti et al. identified image features associated with a poor prognosis. Li et al. used the LASSO method to identify features included in a Cox model for the prediction of OS. In the present study, the LASSO method was also used to identify 7 image features that could be used to build the Rad-score. Then, the Rad-score could be divided into categories indicating low, moderate, and high risk, and each category was associated with distinct DFS. Previous studies also reported that radiomics signatures could be stratified based on risk levels, offering a prognostic value.

Still, radiomics alone might not be the best predictor for GC prognosis, and its combination with traditional clinical prognostic factors might improve its predictive ability. Indeed, in the present study, positive lymph nodes and CA-125 were found to be independently associated with DFS along with the Rad-score. The presence of positive lymph nodes is a well-known poor prognostic factor for solid cancers, including GC. CA-125 is also associated with the prognosis of GC. According to the WHO 2019 classification, some of the selected changes in the new classification
This study had limitations. First, this study was a single-center, retrospective study, and multicenter validation should be performed in the future. Second, due to the limited number of patients and follow-up time, OS could not be assessed. The relationship between the Rad-score and post-operative chemotherapy for gastric cancer will also have to be examined in the future.

In conclusion, the Rad-score was independently associated with DFS after gastrectomy. Its predictive ability was higher when combined with traditional clinical factors. The nomogram chart established in our study could be an effective tool for clinical prediction of DFS after gastrectomy.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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### Supplementary Table S1. Rad-score values of high, moderate, or low recurrence/metastasis risks in the training group (n = 124)

|                    | High risk (n = 31) | Moderate risk (n = 56) | Low risk (n = 37) |
|--------------------|--------------------|------------------------|------------------|
| Rad-score          | $(-1.63, -0.63)$   | $(-0.53, 0.67)$         | $(0.73, 1.81)$   |
| Recurrence/metastasis | 24 (77.4%)    | 27 (48.2%)          | 7 (18.9%)        |
| Relative risk      | 1.67 (high vs. moderate) | 2.84 (moderate vs. low) | 4.73 (high vs. low) |
| Rad-score $P$      | $<.001$ (high vs. moderate) | $<.001$ (moderate vs. low) | $<.001$ (high vs. low) |

### Supplementary Table S2. Rad-score values of high, moderate, or low recurrence/metastasis risks in the validation group (n = 55)

|                    | High risk (n = 6) | Moderate risk (n = 19) | Low risk (n = 30) |
|--------------------|-------------------|------------------------|------------------|
| Rad-score          | $(-0.89, -0.60)$  | $(-0.52, -0.02)$       | $(0.04, 1.42)$   |
| Recurrence/metastasis | 5 (83.3%)    | 11 (57.9%)           | 10 (33.3%)       |
| Relative risk      | 1.78 (high vs. moderate) | 1.50 (moderate vs. low) | 2.67 (high vs. low) |
| Rad-score $P$      | $<.001$ (high vs. moderate) | $<.001$ (moderate vs. low) | $<.001$ (high vs. low) |

### Supplementary Table S3. Rad-score values of high, moderate, or low recurrence/metastasis risks in the overall cases (n = 179)

|                    | High risk (n = 37) | Moderate risk (n = 62) | Low risk (n = 80) |
|--------------------|-------------------|------------------------|------------------|
| Rad-score          | $(-4.81, -0.60)$  | $(-0.60, 0.18)$        | $(0.22, 5.73)$   |
| Recurrence/metastasis | 29 (78.4%)    | 33 (53.2%)           | 22 (27.5%)       |
| Relative risk      | 1.62 (high vs. moderate) | 1.93 (moderate vs. low) | 3.12 (high vs. low) |
| Rad-score $P$      | $<.001$ (high vs. moderate) | $<.001$ (moderate vs. low) | $<.001$ (high vs. low) |