

ORIGINAL ARTICLE

A Prediction Model for Clinical Outcomes of COVID-19 Hospitalized Patients: Construction and Accuracy Assessment

Han Chen [#], Meng-jia Chen [#], Li-qun Ling [#], Jian-rong Yang, Hai-xia Huang, Jia-jing Zhou, Ning Yang, Mei-juan Zhang

*[#] These authors contributed equally and should be considered co-first authors
Department of Laboratory Medicine, The First Affiliated Hospital of Wenzhou Medical University, Wenzhou, China*

SUMMARY

Background: The coronavirus disease 2019 (COVID-19) pandemic spread rapidly with considerable morbidity nationwide since China's liberalization in December 2022. Our work has focused on identifying different predictive factors from the laboratory examination of critically ill patients, and forecasting the unfavorable outcome of critically ill patients with COVID-19 through a combined diagnosis of biological markers.

Methods: We conducted a retrospective study at the Department of First Affiliated Hospital of Wenzhou Medical University, China, from December 24, 2022, to January 10, 2023, where 434 critically ill patients who met the inclusion criteria were involved. Machine analysis was employed to search for the parameters with the highest predictive value to calculate COVID-19 mortality by exploiting 66 typical laboratory results.

Results: Combined diagnosis of serum albumin (ALB), lactate dehydrogenase (LDH), direct bilirubin (Dbil), ferritin, pulse oxygen saturation (SpO₂), and neutrophil count (NEUT#) was evaluated, and the result with the highest predictive value (NEUT#) was selected as the predictor for COVID-19 mortality with a sensitivity of 89.2% and a specificity of 77.4%.

Conclusions: The increased levels of LDH, Dbil, ferritin, and NEUT#, along with lowered ALB and SpO₂ levels are the most decisive variables for forecasting the mortality for COVID-19 according to our machine-learning-based model. The combined diagnosis could be used to improve further diagnostic performance.
(Clin. Lab. 2024;70:xx-xx. DOI: 10.7754/Clin.Lab.2023.230721)

Correspondence:

Mei-juan Zhang
Department of Clinical Laboratory
Key Laboratory of Clinical Laboratory Diagnosis and Translational Research of Zhejiang Province
The First Affiliated Hospital of Wenzhou Medical University
Wenzhou
Zhejiang
China
Email: 18767482298@126.com

Supplementary Data

Table S1. Summary of the therapeutic measures, demographic and clinical features of patients with COVID-19.

		Non-recovery group (n = 120)	Recovery group (n = 314)
Demographic and clinical features			
Age (Mean ± SD)		76.140 ± 10.445	70.120 ± 14.190
Gender n (%)	male	85 (70.8%)	200 (63.7%)
	female	35 (29.2%)	114 (36.3%)
Length of stay days (Mean ± SD)		11.660 ± 8.750	11.830 ± 9.115
Clinical assessment at admission n (%)	Padua score system		
	< 4	97 (80.8%)	282 (89.8%)
	≥ 4	23 (19.2%)	32 (10.2%)
	Caprini score system		
	0 - 1	7 (5.8%)	7 (2.2%)
	2	3 (2.5%)	11 (3.5%)
	3 - 4	14 (11.7%)	25 (8.0%)
	≥ 5	11 (9.2%)	14 (4.5%)
	ADL score system		
	100	0 (0.0%)	41 (13.1%)
	≥ 60	4 (3.3%)	149 (47.5%)
	40 - 60	13 (10.8%)	58 (18.5%)
	20 - 40	11 (9.2%)	24 (7.6%)
< 20	92 (76.7%)	42 (13.4%)	
Comorbidities n (%)	obesity (BMI > 30 kg/m²)	7 (5.8%)	16/(5.1%)
	hypertension	71 (59.2%)	177/(56.4%)
	diabetes	40 (33.3%)	109/(34.7%)
	cardiovascular diseases	20 (16.7%)	61/(19.4%)
	chronic kidney diseases	16 (13.3%)	30/(9.6%)
	malignancy	17 (14.2%)	29/(9.2%)
	cerebral diseases	35 (29.1%)	41/(13.1%)
Symptoms n (%)	fever	82 (68.3%)	152 (48.4%)
	cough	77 (64.2%)	239 (76.1%)
	dyspnea	84 (70.0%)	153 (48.7%)
	asthenia	8 (6.7%)	24 (7.6%)
	chills	12 (10.0%)	28 (8.9%)
	nausea and vomiting	3 (2.5%)	10 (3.2%)
	divisor change	10 (8.3%)	9 (2.9%)
	snot/stuffy nose	3 (2.5%)	9 (2.9%)
	ache	6 (5.0%)	40 (12.7%)
diarrhea	3 (2.5%)	7 (2.2%)	

Table S1. Summary of the therapeutic measures, demographic and clinical features of patients with COVID-19 (continued).

		Non-recovery group (n = 120)	Recovery group (n = 314)
Infection situation n (%)	respiratory infection	30 (25.0%)	33 (10.5%)
	bloodstream infection	13 (10.8%)	6 (1.9%)
	urinary infection	2 (1.7%)	7 (2.2%)
	TB-infected T cells	2 (1.7%)	16 (5.1%)
	mycobacterium tuberculosis	1 (0.8%)	(0.3%)
Therapeutic measure			
Antiviral drug n (%)	paxlovid	50 (41.7%)	109 (34.7%)
	azvudine	14 (11.7%)	40 (12.7%)
	monapivir	29 (24.2%)	85 (27.1%)
	tozumab	9 (7.5%)	14 (4.5%)
Hormone steroid n (%)	methylprednisolone	88 (73.3%)	138 (43.9%)
	dexamethasone	24 (20.0%)	79 (25.2%)
Oxygen inhalation mode n (%)	mechanical ventilation (MV)	83 (69.2%)	36 (11.5%)
	mask oxygen therapy	76 (63.3%)	119 (37.9%)
	nasal oxygen therapy	36 (30.0%)	238 (75.8%)
Anticoagulant drugs n (%)	heparin	80 (66.7%)	132 (42.0%)
Nutritional support n (%)	r-Globulin	10 (8.3%)	18 (5.7%)
	albumin	84 (70.0%)	118 (37.6%)
	vitamin C	86 (71.7%)	157 (50.0%)
	vitamin B	83 (69.2%)	156 (49.7%)
Antibacterials n (%)	linezolid	12 (10.0%)	9 (2.9%)
	imipenem	29 (24.2%)	15 (4.8%)
	ceftriaxone	20 (16.7%)	95 (30.3%)
	sulperazone	64 (53.3%)	119 (37.9%)
	meropenem	30 (25.0%)	31 (9.9%)
	piperacillin/tazobactam	30 (25.0%)	41 (13.1%)
	cefoperazone/sulbactam	8 (6.7%)	9 (2.9%)

Padua score system: low risk (< 4 points), high risk (\geq 4 points).

Caprini score system: low risk (0 - 1 point), medium risk (2 points), high risk (3 - 4 points), and extremely high risk (\geq 5 points). ADL score system: self-care (100 points), basic self-care (60 points), life needs assistance (40 - 60 points), life needs great assistance (20 - 40 points), life is completely dependent (< 20 points).

Cardiovascular diseases: atrial fibrillation, coronary heart disease, myocardial infarction and heart failure.

Chronic kidney diseases: uremia, glomerulonephritis, nephrotic syndrome, and chronic renal insufficiency.

Malignancy: lung, liver, breast, brain, stomach, bone, leukemia, and intestine.

Cerebral diseases: schizophrenia, history of cerebral infarction.

Parkinson's disease, cerebral aneurysm, pituitary tumor, hemorrhage history, and Alzheimer's disease.

Pulmonary diseases: tuberculosis, pneumonia, COPD, pulmonary nodules, pulmonary hypertension and emphysema.

Table S2. Laboratory hematology indices between the recovery and non-recovery groups.

Laboratory examinations mean \pm SD	Total (n = 434)	Non-recovery group (n = 120)	Recovery group (n = 314)	P
SpO ₂ (%)	93.088 \pm 8.574	89.360 \pm 10.707	94.513 \pm 7.123	< 0.001
PaO ₂ (mmHg)	89.619 \pm 35.604	80.837 \pm 34.951	92.976 \pm 35.331	0.001
NT-proBNP (ng/L)	2,937.670 \pm 7,090.444	4,662.791 \pm 9,308.646	2,278.388 \pm 5,918.442	0.01
hs-TnT (ng/L)	87.908 \pm 491.755	198.556 \pm 923.167	45.622 \pm 63.512	0.072
Mb (ng/mL)	453.667 \pm 1,618.387	924.608 \pm 2,966.537	273.689 \pm 399.991	0.018
CRP (mg/L)	98.923 \pm 73.173	130.089 \pm 90.438	87.012 \pm 61.504	< 0.001
PCT (ng/mL)	4.191 \pm 15.256	7.929 \pm 21.480	2.762 \pm 11.795	0.014
PT (second)	14.126 \pm 3.494	15.136 \pm 4.031	13.740 \pm 3.190	0.001
Fib (g/L)	5.606 \pm 3.114	5.648 \pm 2.041	5.590 \pm 3.439	0.863
D-Dimer (mg/L)	1.840 \pm 2.341	2.740 \pm 3.031	1.496 \pm 1.913	< 0.001
Ferritin (ng/mL)	1,430.067 \pm 1,676.666	2,070.752 \pm 2,873.237	1,185.21 \pm 729.936	0.001
IL-2 (pg/mL)	0.795 \pm 0.934	0.765 \pm 1.043	0.807 \pm 0.890	0.678
IL-4 (pg/mL)	0.224 \pm 0.54	0.287 \pm 0.906	0.199 \pm 0.315	0.305
IL-6 (pg/mL)	318.825 \pm 1,028.082	591.564 \pm 1,308.434	214.594 \pm 878.559	0.004
IL-10 (pg/mL)	19.068 \pm 79.540	22.395 \pm 67.380	17.797 \pm 83.787	0.591
TNF- α (pg/mL)	0.444 \pm 1.290	0.423 \pm 1.219	0.453 \pm 1.318	0.83
IFN- γ (pg/mL)	1.865 \pm 4.801	1.232 \pm 2.152	2.107 \pm 5.469	0.09
Lymphocyte count ($\times 10^9/L$)	0.941 \pm 2.087	1.090 \pm 3.926	0.884 \pm 0.392	0.567
T cell (CD3+) (%)	57.619 \pm 12.613	54.420 \pm 14.387	58.842 \pm 11.660	0.003
T cell (CD4+) (%)	34.436 \pm 9.869	32.410 \pm 11.588	35.210 \pm 9.029	0.018
T cell (CD8+) (%)	23.653 \pm 9.225	22.524 \pm 10.008	24.085 \pm 8.887	0.115
T cell (CD4+)/T cell (CD8+)	1.873 \pm 1.296	2.015 \pm 1.869	1.819 \pm 0.992	0.277
B cell (CD3-CD19+) (%)	17.612 \pm 9.014	19.395 \pm 11.034	16.931 \pm 8.028	0.027
NK cell (CD3-CD56+CD16+) (%)	23.723 \pm 11.582	25.065 \pm 12.511	23.210 \pm 11.185	0.136
WBC ($\times 10^9/L$)	8.143 \pm 5.146	10.555 \pm 6.260	7.221 \pm 4.318	< 0.001
Eosinophil count (EO#) ($\times 10^9/L$)	0.024 \pm 0.0579	0.013 \pm 0.030	0.026 \pm 0.057	0.002
Neutrophil count (NEUT#) ($\times 10^9/L$)	6.871 \pm 5.003	9.511 \pm 6.058	5.908 \pm 4.183	< 0.001
Monocyte count (MONO#) ($\times 10^9/L$)	0.457 \pm 0.309	0.493 \pm 0.380	0.443 \pm 0.279	0.135
Lymphocyte count (LYMPH#) ($\times 10^9/L$)	0.842 \pm 0.509	0.669 \pm 0.435	0.904 \pm 0.527	< 0.001
Basophil count (BASO#) ($\times 10^9/L$)	0.006 \pm 0.008	0.004 \pm 0.008	0.006 \pm 0.001	0.017
RBC ($\times 10^{12}/L$)	4.016 \pm 0.738	3.897 \pm 0.764	4.062 \pm 0.724	0.037
HGB (g/L)	122.150 \pm 21.767	118.420 \pm 23.031	123.580 \pm 21.129	0.027
HCT (L/L)	0.364 \pm 0.063	0.356 \pm 0.067	0.367 \pm 0.062	0.088
MCV (fL)	91.077 \pm 6.558	91.637 \pm 6.804	90.864 \pm 6.461	0.273
MCH (pg)	30.551 \pm 2.437	30.495 \pm 2.679	30.572 \pm 2.342	0.768
MCHC (g/L)	335.380 \pm 9.299	332.590 \pm 11.055	336.450 \pm 8.308	0.001
RDW (%)	13.413 \pm 1.210	13.798 \pm 1.447	13.266 \pm 1.074	< 0.001
PLT ($\times 10^9/L$)	186.500 \pm 96.159	191.660 \pm 123.666	184.540 \pm 83.445	0.561

Table S2. Laboratory hematology indices between the recovery and non-recovery groups (continued).

Laboratory examinations mean \pm SD	Total (n = 434)	Non-recovery group (n = 120)	Recovery group (n = 314)	p
TBil ($\mu\text{mol/L}$)	11.728 \pm 5.614	13.535 \pm 7.214	11.038 \pm 4.699	0.001
DBil ($\mu\text{mol/L}$)	3.386 \pm 2.777	4.720 \pm 4.177	2.876 \pm 1.759	< 0.001
TP (g/L)	60.571 \pm 6.528	57.938 \pm 7.032	61.577 \pm 6.039	< 0.001
ALB (g/L)	31.519 \pm 4.773	28.350 \pm 4.154	32.730 \pm 4.431	< 0.001
ALT (U/L)	45.729 \pm 97.929	76.813 \pm 176.870	33.850 \pm 29.346	0.009
AST (U/L)	80.890 \pm 378.534	182.430 \pm 710.752	42.080 \pm 26.413	0.033
ALP (U/L)	86.010 \pm 46.507	99.203 \pm 48.410	80.968 \pm 44.820	< 0.001
GGT (U/L)	72.691 \pm 91.919	89.781 \pm 118.281	66.160 \pm 78.832	0.045
UREA (mmol/L)	10.400 \pm 8.210	15.058 \pm 9.784	8.619 \pm 6.735	< 0.001
CR ($\mu\text{mol/L}$)	137.720 \pm 182.258	183.482 \pm 188.054	120.232 \pm 177.196	0.002
UA ($\mu\text{mol/L}$)	321.813 \pm 156.554	378.627 \pm 191.655	300.101 \pm 135.018	< 0.001
CK (U/L)	368.748 \pm 1,497.321	688.962 \pm 2,766.860	246.374 \pm 369.615	0.083
LDH (U/L)	405.075 \pm 191.909	544.060 \pm 245.287	351.960 \pm 133.560	< 0.001
K (mmol/L)	3.939 \pm 0.533	4.134 \pm 0.634	3.864 \pm 0.469	< 0.001
Na (mmol/L)	139.566 \pm 5.824	141.743 \pm 7.326	138.734 \pm 4.901	< 0.001
Cl (mmol/L)	105.283 \pm 6.389	107.717 \pm 7.847	104.353 \pm 5.470	< 0.001
Ca (mmol/L)	2.052 \pm 0.131	2.006 \pm 0.146	2.069 \pm 0.120	< 0.001
Pi (mmol/L)	1.022 \pm 0.307	1.078 \pm 0.381	1.001 \pm 0.270	0.044
GLU (mmol/L)	10.239 \pm 4.913	11.146 \pm 5.834	9.892 \pm 4.475	0.035
CHOL (mmol/L)	3.955 \pm 0.981	3.844 \pm 1.107	3.998 \pm 0.927	0.143
TRIG (mmol/L)	1.558 \pm 0.879	1.616 \pm 0.678	1.536 \pm 0.945	0.398
HDL-C (mmol/L)	0.948 \pm 0.237	0.942 \pm 0.257	0.950 \pm 0.229	0.773
LDL-C (mmol/L)	2.486 \pm 0.732	2.386 \pm 0.778	2.525 \pm 0.711	0.076
T4 (nmol/L)	123.237 \pm 25.711	114.772 \pm 24.917	126.472 \pm 25.308	< 0.001
T3 (nmol/L)	0.869 \pm 0.308	0.738 \pm 0.236	0.919 \pm 0.318	< 0.001
TSH (mIU/L)	1.147 \pm 1.475	0.877 \pm 0.708	1.250 \pm 1.667	0.018
FT4 (pmol/L)	13.819 \pm 2.489	13.562 \pm 2.942	13.918 \pm 2.290	0.234
FT3 (pmol/L)	3.743 \pm 0.618	3.579 \pm 0.619	3.806 \pm 0.608	0.001

SpO₂ - pulse oxygen saturation, PaO₂ - alveolar oxygen partial pressure, NT-proBNP - n-terminal pro-brain natriuretic peptide, hs-TnT - high-sensitivity troponin T, Mb - myoglobin, CRP - C-reactive protein, PCT - procalcitonin, PT - prothrombin time, Fib - fibrinogen, IL - interleukin, TNF- α - tumor necrosis factor- α , IFN- γ - interferon- γ , WBC - white blood cell count, RBC - red blood cell count, HGB - hemoglobin, HCT - hematocrit, MCV - mean corpuscular volume, MCH - mean corpuscular hemoglobin, MCHC - mean corpuscular hemoglobin concentration, RDW - red cell distribution width, PLT - platelet, TBil - total bilirubin, DBil - direct bilirubin, TP - total protein, Alb - albumin, ALT - alanine aminotransferase, AST - aspartate aminotransferase, ALP - alkaline phosphatase, γ -GT - γ -glutamyl transpeptidase, Cr - creatinine, UA - uric acid, CK - creatine kinase, LDH - lactate dehydrogenase, K - potassium, Na - sodium, Cl - chloride, Ca - calcium, Pi - phosphorus, Glu - glucose, CHOL - cholesterol, TRIG - triglyceride, HDL-C - high-density lipoprotein cholesterol, LDL-C - low-density lipoprotein cholesterol, T4 - thyroxine, T3 - triiodothyronine, TSH - thyroid stimulating hormone, FT4 - free thyroxine, FT3 - free triiodothyronine.

Table S3. Multivariate analysis for predicting the risk of recovery in COVID-19 patients of ICU admission.

Variables	OR	95% CI	p
SpO ₂	0.914	0.863 - 0.967	0.002
PaO ₂	0.995	0.984 - 1.007	0.419
NT-proBNP	1.000	1.000 - 1.000	0.405
Mb	1.000	1.000 - 1.001	0.536
CRP	0.998	0.992 - 1.004	0.447
PCT	0.985	0.962 - 1.009	0.228
PT	0.97	0.853 - 1.103	0.639
D-Dimer	1.004	0.833 - 1.210	0.969
Ferritin	1.001	1.000 - 1.001	0.004
IL-6	1.000	0.999 - 1.000	0.098
T cell (CD3+)	1.007	0.964 - 1.053	0.747
T cell (CD4+)	0.974	0.921 - 1.030	0.355
B cell (CD3-CD19+)	0.970	0.923 - 1.020	0.235
WBC	1.015	0.645 - 1.599	0.948
Eosinophil count (EO#)	0.003	0 - 144421.357	0.524
Neutrophil count (NEUT#)	0.999	0.627 - 1.593	0.998
Lymphocyte count (LYMPH#)	0.540	0.173 - 1.686	0.289
Basophil count (BASO#)	0.000	0 - 3.592E+22	0.650
RBC	0.006	0.001 - 0.725	0.036
HGB	1.177	1.011 - 1.369	0.036
MCHC	0.916	0.85 - 0.986	0.020
RDW	2.191	0.663 - 7.243	0.198
RDW-SD	0.705	0.492 - 1.01	0.057
TBil	1.019	0.853 - 1.217	0.833
DBil	1.035	0.702 - 1.527	0.861
TP	1.032	0.95 - 1.122	0.456
ALB	0.823	0.714 - 0.948	0.007
ALT	1.003	0.992 - 1.015	0.595
AST	1.001	0.989 - 1.013	0.886
ALP	1.005	0.992 - 1.018	0.458
GGT	0.997	0.989 - 1.005	0.417
UREA	1.006	0.929 - 1.089	0.891
CR	1.000	0.998 - 1.003	0.739
UA	1.002	0.999 - 1.006	0.200
LDH	1.004	1.001 - 1.007	0.003
K	2.162	0.899 - 5.198	0.085
Na	1.048	0.914 - 1.201	0.504
Cl	1.011	0.884 - 1.155	0.877
Ca	0.282	0.01 - 8.331	0.463
Pi	0.706	0.174 - 2.857	0.626
T4	1.006	0.989 - 1.024	0.471
T3	0.276	0.039 - 1.953	0.197
TSH	0.854	0.522 - 1.399	0.531
FT3	2.295	0.863 - 6.102	0.096

OR - odds ratio, CI - confidence interval.