Derivation and Validation of a Predictive Score for Disease Worsening in Patients with COVID-19

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The prospective observational cohort study COMPASS-COVID-19 aimed to develop a risk assessment model for early identification of hospitalized COVID-19 patients at risk for worsening disease. Patients with confirmed COVID-19 (n = 430) hospitalized between March 18 and April 21, 2020 were divided in derivation (n = 310) and validation (n = 120) cohorts. Two groups became evident: (1) good prognosis group (G-group) with patients hospitalized at the conventional COVID-19 ward and (2) Worsening disease group (W-group) with patients admitted to the intensive care unit (ICU) from the emergency departments. The study end point was disease worsening (acute respiratory failure, shock, myocardial dysfunction, bacterial or viral coinfections, and acute kidney injury) requiring ICU admission. All patients were routinely evaluated for full blood count, prothrombin time, fibrinogen, D-dimers, antithrombin (AT), and protein C activity. Data from the first hospitalization day at the conventional ward or the ICU were analyzed. Cardiovascular risk factors and comorbidities were routinely registered. Obesity, hypertension, diabetes and male gender, increased fibrinogen and...
D-dimers, thrombocytopenia, AT deficiency, lymphopenia, and an International Society on Thrombosis and Haemostasis (ISTH) score for compensated disseminated intravascular coagulation score (cDIC-ISTH) ≥5 were significant risk factors for worsening disease. The COMPASS-COVID-19 score was derived from multivariate analyses and includes obesity, gender, hemoglobin, lymphocyte, and the cDIC-ISTH score (including platelet count, prothrombin time, D-dimers, AT, and protein C levels). The score has a very good discriminating capacity to stratify patients at high and low risk for worsening disease, with an area under the receiver operating characteristic curve value of 0.77, a sensitivity of 81%, and a specificity of 60%. Application of the COMPASS-COVID-19 score at the validation cohort showed 96% sensitivity. The COMPASS-COVID-19 score is an accurate clinical decision-making tool for an easy identification of COVID-19 patients being at high risk for disease worsening.

**Introduction**

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causes coronavirus disease 2019 (COVID-19). The SARS-CoV-2 pandemic has put the health care systems worldwide under extremely high stress. COVID-19 is characterized by acute pneumonia which may progress to respiratory failure and life-threatening complications, including acute respiratory distress syndrome and multisystem organ failure with fatal outcome. COVID-19 should be regarded as a systemic disease involving multiple systems. COVID-19 is associated with excessive inflammation, platelet activation, endothelial dysfunction, blood coagulation activation, and fibrin formation. Current management of patients hospitalized in an intensive care unit (ICU) is based on supportive care and the mortality rate may be high. Blood hypercoagulability—documented by an increase in D-dimers and a decrease in antithrombin (AT)—is frequently encountered among COVID-19 patients. Identification of patients with COVID-19 being at high risk for clinical deterioration is a challenging issue for an earlier adapted treatment and positive clinical outcome. These patients could benefit from earlier appropriate oxygen support, antithrombotic agents, and compassionate-use therapies, including antiretrovirals, anti-inflammatory drugs, immunomodulatory compounds, and convalescent plasma.

In this prospective observational study conducted at the COVID-19 center of Tenon University Hospital in Paris, we aimed to identify the most relevant clinical and hematological risk factors for worsening of COVID-19 by constructing an accurate risk assessment tool.

**Methods**

**Participants**

In the set-up of the COVID-19 center at Tenon University Hospital (APHP, Sorbonne University, Paris), we designed a prospective observational cohort study and enrolled all admitted patients in two phases: (1) between March 18 and April 5, 2020 to constitute the derivation cohort and (b) between April 6 and April 21 to constitute the validation cohort which was composed only of new patients. According to the follow-up during the course of the disease, two groups became evident: (1) good prognosis group (G-group) with patients hospitalized at the conventional COVID-19 ward. G-group patients were assessed on the first admission day. (2) Worsening disease group (W-group) included patients admitted to the ICU from the emergency department since they presented with clinically deteriorated COVID-19. W-group patients were assessed on the first day of admission.

**Definitions**

All patients had laboratory-confirmed COVID-19 infection and were hospitalized either in the conventional COVID-19 ward of the medical department or in the COVID-19 ICU. A confirmed case of COVID-19 was defined by a positive result on a reverse transcriptase polymerase chain reaction (rt-PCR) assay from a specimen collected on a nasopharyngeal swab and imaging of well-documented pneumonia according to the Fleischner Society consensus statement. Pregnant women, patients receiving anticoagulant treatment, and patients with cytopenia due to current anticancer treatment were excluded. All patients hospitalized in the conventional medical department or in the ICU routinely received thromboprophylaxis with body-weight-adapted enoxaparin. All clinical and biological data were cross-checked with the electronic files using the ORBIS software (Agfa Healthcare) and the GLIMS laboratory information system (MIPS France) of Tenon University Hospital.

**Hematological Parameters**

In the set-up of the COVID-19 center at Tenon University Hospital, all patients were evaluated daily with a “COAG-COVID” panel composed of tests of various parameters: prothrombin time (PT), fibrinogen, D-dimers, AT activity, protein C (PC) activity, and platelet count. These tests are predictors of compensated disseminated intravascular coagulation (DIC) according to the International Society on Thrombosis and Haemostasis (ISTH) score (compensated DIC-ISTH). In addition to platelets, all other hemogram
parameters were also analyzed. Blood samples were routinely obtained via an atraumatic antecubital venipuncture or from the central vein catheter. For coagulation tests, blood was collected in 3.5 mL Vacuette tubes containing 0.109 mol/L trisodium citrate—one volume trisodium citrate to nine volumes of blood—(Greiner Bio-One, Courtaboeuf, France) and centrifuged at 2,000 g for 20 minutes at room temperature for platelet-poor plasma (PPP) preparation. Within 30 minutes upon preparation, PPP samples were assessed for blood coagulation tests on the STA-R MAX instrument from Stago (Asnières-sur-Seine, France) according to manufacturer’s instructions. PT was assessed with chromometric assay using the STA-Neoptimal reagent (ref: 01165). Fibrinogen was measured with the Clauss-based chromometric assay using the Liquid FIB reagent (ref: 00673). D-dimers were measured with turbidimetric assay using the STA-Latest D-Di Plus reagent (ref: 00662). AT and PC activities were measured with the amidolytic assays STACHROM ATIII (ref: 00596, from Stago, Asnières, France) and BIOPHEN PC (LRT) (ref: 221205, from Hyphen BioMed, Neuville-sur-Oise, France), respectively. Hemogram parameters and platelet count were assessed on whole blood collected in 4 mL EDTA BD Vacutainer tubes (Becton-Dickinson, Le Pont-de-Claiix, France) using the Sysmex XN-3100 instrument (Paris, France). All hematological tests were performed at the ISO certified Central Haematological Laboratory of Thrombosis Center at Tenon University Hospital in Paris.

Ethics
The protocol of the study was in accordance with the commitment of the Helsinki Declaration and all patients received care according to the recommended institutional practice during the COVID-19 pandemic. All hematological tests were performed in the frame of routine monitoring of patients as decided by the local institutional board for the management of the COVID-19 patients. This study was approved by the institutional ethics board. The observational design of the study did not impose the need for getting informed consent from individual patients.

Outcomes
The study end point was disease worsening requiring ICU admission. Disease worsening requiring ICU admission was defined according to the following criteria, acute hypoxic respiratory failure judged on the basis of increased need for oxygen supply more than 9 L/minute or clinical signs of respiratory insufficiency (shortness of breath, respiratory rate \( \geq 30 \) times/min), arterial oxygen saturation (resting status) \( \leq 92\% \), shock, myocardial dysfunction, bacterial or viral coinfections, and acute kidney injury.

Statistical Analysis
Data from the first hospitalization day for the G-group and the first day on ICU admission for the W-group were analyzed. The normal ranges of the COAG-COVID panel of tests have been established by the Thrombosis Center of Tenon University Hospital, according to the requirements for the good quality of laboratory practice. The number of patients included in the derivation cohort was calculated according to the following assumptions: (1) the model had to be constructed according to the rule of thumb, the so-called events per variable (EPV) 10–1 and (2) less than 10 variables should be included in the model in order for it to be easy to use.24–26 Thus, at least 70 patients were required to be enrolled in the W-group to respond to the above conditions accommodating at maximum a seven-variable model. Continuous variables were summarized as median (interquartile range) and categorical variables as frequency and percentage. Because of the deviation from normality (as evidenced by the Shapiro–Wilk test), the comparison of continuous variables between patients with worsening disease and those hospitalized at the conventional ward was performed using the Mann–Whitney–Wilcoxon test for independent samples. Regarding the associations between disease worsening and hematological parameters at baseline, the latter were converted to binary variables on the basis of laboratory normal values. Univariate and multivariate logistic regression analyses were performed to estimate the independent associations between disease worsening (dependent variable) and the examined hematological parameters (independent variables) as binary variables: 1 (yes) or 0 (no). In the multivariate approach aiming to create a score predicting disease worsening, stepwise selection of variables was performed on the basis of the Akaike information criterion (AIC). To obtain the score, \( \beta \) coefficients of the final logistic regression model were rounded and rescaled from the logarithm of the odds ratios (ORs). Receiver operating characteristic (ROC) curve analysis was subsequently undertaken; the area under the ROC curve (AUC) was estimated to evaluate model discrimination performance. The optimal cut-off level was identified through the maximization of unweighted Youden’s index by calculating sensitivity, specificity, positive predictive value, (PPV) and negative predictive value (NPV). Calibration of the model was examined with the Hosmer–Lemeshow test and the respective plot of expected versus observed probability was constructed, for the G-group and W-group. The level of statistical significance was set at 0.05. Data were analyzed using the STATA/SE version 13 statistical software (StataCorp., College Station, Texas, United States).

Results
Derivation Cohort
Among 330 patients with confirmed COVID-19 disease, 310 patients who responded to the inclusion criteria were enrolled in the derivation cohort. The remaining 20 patients were excluded because of pregnancy (\( n = 5 \)), pancytopenia due to chemotherapy (\( n = 6 \)), or oral anticoagulant treatment with direct oral anticoagulants or vitamin K antagonists (\( n = 9 \)). The G-group included 208 patients. The W-group consisted of 102 patients; 87% of these patients were admitted to the ICU directly from the emergency department. Males were 113 out of 208 patients in the G-group and 76 out of 102 patients in the W-group. Age ranged from 19 to 95 years in the G-group and from 30 to 93 years in the W-group.
Validation Cohort

The validation cohort included 120 patients stratified in the G-group (n = 89) and the W-group (n = 31); 90% of patients in the W-group were admitted to the ICU directly from the emergency department. Males were 58 out of 89 patients in the G-group and 25 out of 31 patients in the W-group. Age ranged from 21 to 95 years in the G-group and from 30 to 98 years in the W-group.

The derivation and validation cohorts were comparable regarding the age and sex distribution in each one of the two groups (G- and W-groups). Detailed epidemiological, clinical, and hematological characteristics of the derivation and validation cohorts are shown in Table 1. Very few patients received compassionate or antiviral treatments. Among the G-group patients, five received treatment with lopinavir-ritonavir, one was treated with remdesivir, and another one received hydroxychloroquine. Among the patients in W-group, only four received lopinavir-ritonavir. Upon hospitalization all patients received thromboprophylaxis with low-molecular-weight heparin (LMWH; enoxaparin). The dose of enoxaparin was adapted according to the evolution of D-dimers and the levels of the anti-Xa activity. Moreover, patients with AT deficiency (AT activity lower than 50%) upon admission or during hospitalization received treatment with AT concentrate according to the protocol published elsewhere.14

In both cohorts, there were no missing values of the COAG-COVID biomarkers and clinical predictors. A follow-up of at least 12 days was predicted. However, the follow-up for the most recently enrolled patients was shorter because France was still at the peak of COVID-19 public health crisis when the database closed and data analysis was performed. Male gender representation was significantly higher in the W-group as compared with the G-group. Obesity (body mass index [BMI] > 30), arterial hypertension, and diabetes were significantly more frequent in the W-group as compared with the G-group. Chronic renal insufficiency and cardiovascular disease were more frequent in the W-group as compared with the G-group. Interestingly, very few patients in both groups were active smokers. Data are summarized in Table 1.

### Derivation of the COMPASS-COVID-19 Risk Assessment Model

In the derivation cohort, compensated DIC was diagnosed in 8.2% of patients in the G-group and in 28.2% of patients in the W-group (p = 0.001; Table 1). Compared with the G-group, the patients in the W-group had significantly lower levels of AT, PC, platelets, lymphocyte, monocyte, and red blood cell counts, as well as hemoglobin and hematocrit. They had significantly higher levels of fibrinogen, D-dimers, white blood cells, and neutrophil counts. No difference was noted in eosinophil and basophil counts. Data are summarized in Table 2.

### Table 1 Demographic data, cardiovascular risk factors, comorbidities, and DIC rates in hospitalized COVID-19 patient enrolled in the derivation cohort hospitalized in conventional ward (G-group) or presenting worsening disease (W-group)

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Derivation cohort</th>
<th>Validation cohort</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G-group</td>
<td>W-group</td>
<td>p-Value</td>
</tr>
<tr>
<td></td>
<td>(n = 208)</td>
<td>(n = 102)</td>
<td></td>
</tr>
<tr>
<td>Gender male</td>
<td>54.3% (113/208)</td>
<td>74.5% (76/102)</td>
<td>0.06</td>
</tr>
<tr>
<td>Age (y)</td>
<td>19–95 (median: 66)</td>
<td>30–93 (median: 61)</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular risk factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>39.5% (82/208)</td>
<td>64.6% (66/102)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes</td>
<td>15.8% (33/208)</td>
<td>33.3% (34/102)</td>
<td>0.006</td>
</tr>
<tr>
<td>Obesity</td>
<td>7.8% (16/208)</td>
<td>31.5% (32/102)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Active smoking</td>
<td>4.4% (9/208)</td>
<td>3.9% (4/102)</td>
<td>0.612</td>
</tr>
<tr>
<td>Comorbidities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronic renal disease</td>
<td>7.3% (17/208)</td>
<td>18.8% (19/102)</td>
<td>0.003</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>8.3% (17/208)</td>
<td>10.7% (11/102)</td>
<td>0.548</td>
</tr>
<tr>
<td>Active cancer</td>
<td>12.6% (26/208)</td>
<td>1.9% (2/102)</td>
<td>0.003</td>
</tr>
<tr>
<td>End-stage renal disease</td>
<td>3.9% (8/208)</td>
<td>8.8% (9/102)</td>
<td>0.105</td>
</tr>
</tbody>
</table>

### Coagulopathy

<table>
<thead>
<tr>
<th>Compensated DIC (DIC/ISTH score ⩾ 5)</th>
<th>Derivation cohort</th>
<th>Validation cohort</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-group</td>
<td>8.2% (17/208)</td>
<td>28.4% (29/102)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>W-group</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; DIC, disseminated intravascular coagulation; ISTH, International Society on Thrombosis and Haemostasis; VTE, venous thromboembolism.

*Values for age are in the minimum and maximum range.
Table 2 Variations of hematological parameters in the conventional group (G-group) and worsening disease group (W-group) of COVID-19 patients

<table>
<thead>
<tr>
<th>Blood coagulation parameters</th>
<th>Derivation cohort</th>
<th>Validation cohort</th>
<th>p-Value</th>
<th>Derivation cohort</th>
<th>Validation cohort</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal range</td>
<td>G-group (n = 208)</td>
<td>W-group (n = 102)</td>
<td>p-Value</td>
<td>G-group (n = 89)</td>
<td>W-group (n = 31)</td>
<td>p-Value</td>
</tr>
<tr>
<td>PT (s)</td>
<td>&lt;13.6</td>
<td>14.0 (13.3–14.8)</td>
<td>14.6 (13.9–15.6)</td>
<td>0.0002</td>
<td>14.6 (13.5–15.7)</td>
<td>14.9 (13.6–16.1)</td>
</tr>
<tr>
<td>Fibrinogen (g/L)</td>
<td>1.8–4.0</td>
<td>5.9 (4.7–7.0)</td>
<td>6.9 (6.0–7.6)</td>
<td>&lt;0.0001</td>
<td>6.1 (5.1–7.2)</td>
<td>7.1 (6.1–7.8)</td>
</tr>
<tr>
<td>D-dimers (ng/mL)</td>
<td>&lt;500 for age</td>
<td>1,171 (608–2,136)</td>
<td>1,881 (1,074–3,662)</td>
<td>&lt;0.0001</td>
<td>2,434 (923–3,082)</td>
<td>2,599 (1,200–3,600)</td>
</tr>
<tr>
<td>Antithrombin (%)</td>
<td>80–120</td>
<td>96 (84–107)</td>
<td>88 (79–99)</td>
<td>0.0003</td>
<td>95 (83–107)</td>
<td>90 (80–100)</td>
</tr>
<tr>
<td>Protein C (%)</td>
<td>70–130</td>
<td>97 (79–113)</td>
<td>88 (71–100)</td>
<td>0.0002</td>
<td>101 (81–115)</td>
<td>101 (80–116)</td>
</tr>
<tr>
<td>Blood cell parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemoglobin (g/dL)</td>
<td>12.0–16.0</td>
<td>12.6 (11.3–13.7)</td>
<td>12.1 (10.4–13.4)</td>
<td>0.019</td>
<td>12.4 (11.2–13.5)</td>
<td>10.5 (8.3–11.8)</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>35.0–47.0</td>
<td>37.1 (34.2–40.3)</td>
<td>35.4 (31.1–38.8)</td>
<td>0.006</td>
<td>38.1 (35.1–41.0)</td>
<td>28.3 (28.3–36.2)</td>
</tr>
<tr>
<td>Red blood cells (× 10^9/L)</td>
<td>4.0–5.2</td>
<td>4.3 (4.0–4.8)</td>
<td>4.2 (3.7–4.6)</td>
<td>0.039</td>
<td>4.5 (4.2–5.1)</td>
<td>3.9 (3.5–4.3)</td>
</tr>
<tr>
<td>Platelets (× 10^9/L)</td>
<td>150–400</td>
<td>240 (179–315)</td>
<td>211 (151–257)</td>
<td>0.0003</td>
<td>272 (182–350)</td>
<td>276 (200–340)</td>
</tr>
<tr>
<td>White blood cells (× 10^9/L)</td>
<td>4.0–10.0</td>
<td>6.8 (5.1–8.7)</td>
<td>7.7 (6.1–10.5)</td>
<td>0.013</td>
<td>6.5 (5.0–8.6)</td>
<td>8.1 (6.9–11.2)</td>
</tr>
<tr>
<td>Neutrophils (× 10^9/L)</td>
<td>1.5–7.0</td>
<td>4.9 (3.4–6.6)</td>
<td>6.2 (4.8–8.9)</td>
<td>0.0001</td>
<td>4.7 (3.2–6.4)</td>
<td>6.5 (4.9–9.1)</td>
</tr>
<tr>
<td>Lymphocytes (× 10^9/L)</td>
<td>1.5–4.0</td>
<td>1.04 (0.74–1.52)</td>
<td>0.76 (0.53–1.10)</td>
<td>&lt;0.0001</td>
<td>1.26 (1.12–1.72)</td>
<td>0.97 (0.52–1.32)</td>
</tr>
<tr>
<td>Monocytes (× 10^9/L)</td>
<td>0.1–1.0</td>
<td>0.49 (0.32–0.68)</td>
<td>0.29 (0.19–0.49)</td>
<td>&lt;0.0001</td>
<td>0.50 (0.33–0.69)</td>
<td>0.30 (0.18–0.51)</td>
</tr>
<tr>
<td>Eosinophils (× 10^9/L)</td>
<td>0.03–0.7</td>
<td>0.02 (0–0.08)</td>
<td>0.01 (0–0.04)</td>
<td>0.004</td>
<td>0.02 (0–0.09)</td>
<td>0.01 (0–0.4)</td>
</tr>
<tr>
<td>Basophils (× 10^9/L)</td>
<td>&lt;0.1</td>
<td>0.01 (0.01–0.02)</td>
<td>0.01 (0–0.02)</td>
<td>0.065</td>
<td>0.01 (0.01–0.02)</td>
<td>0.01 (0–0.02)</td>
</tr>
</tbody>
</table>

Abbreviation: PT, prothrombin time.
Clinical Predictors for Disease Worsening

The univariate analysis showed that the risk for worsening disease was increased in men compared with women: OR = 2.43, 95% confidence interval (CI): 1.44 to 4.10. Among clinical predictors, obesity (OR = 5.44, 95% CI: 2.77–10.67), hypertension (OR = 2.79, 95% CI: 1.69–4.62), and diabetes (OR = 2.13, 95% CI: 1.23–3.69) were significantly related with an increased risk for disease worsening. Surprisingly current smoking was not a significant risk factor for clinical deterioration of COVID-19 patients. Among comorbidities, chronic kidney disease (OR = 2.92, 95%CI:1.40–6.09) was a risk factor for disease worsening (►Table 3).

Table 3 Univariate analysis of COVID-19 patients determining the risk factors associated with worsening disease

<table>
<thead>
<tr>
<th>Examined parameters</th>
<th>Compared categories</th>
<th>OR (95% CI)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Male vs. female</td>
<td>2.43 (1.44–4.10)</td>
<td>0.001</td>
</tr>
<tr>
<td>Age (y)</td>
<td>≥70 vs. &lt;70</td>
<td>0.48 (0.28–0.81)</td>
<td>0.006</td>
</tr>
<tr>
<td>Cardiovascular risk factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obesity</td>
<td>Yes vs. no</td>
<td>5.44 (2.77–10.67)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hypertension</td>
<td>Yes vs. no</td>
<td>2.79 (1.69–4.62)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>Yes vs. no</td>
<td>2.13 (1.23–3.69)</td>
<td>0.007</td>
</tr>
<tr>
<td>Current smoking</td>
<td>Yes vs. no</td>
<td>0.71 (0.19–2.68)</td>
<td>0.614</td>
</tr>
<tr>
<td>Comorbidities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronic kidney disease</td>
<td>Yes vs. no</td>
<td>2.92 (1.40–6.09)</td>
<td>0.004</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>Yes vs. no</td>
<td>1.29 (0.57–2.92)</td>
<td>0.549</td>
</tr>
<tr>
<td>Coagulopathy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compensated DIC-ISTH score ≥ 5 a</td>
<td>Yes vs. no</td>
<td>4.58 (2.09–10.07)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blood coagulation parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT (s)</td>
<td>Elevated &gt;3 seconds compared with the normal limit versus not</td>
<td>2.43 (1.15–5.13)</td>
<td>0.021</td>
</tr>
<tr>
<td>Fibrinogen (g/L)</td>
<td>&gt;4 vs. ≤4</td>
<td>9.50 (2.23–40.54)</td>
<td>0.002</td>
</tr>
<tr>
<td>D-dimers (ng/mL)</td>
<td>Elevated vs. normal in age-specific norm b</td>
<td>7.65 (2.67–21.87)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Protein C (%)</td>
<td>&lt;70 vs. ≥70</td>
<td>2.51 (1.30–4.83)</td>
<td>0.006</td>
</tr>
<tr>
<td>Antithrombin (%)</td>
<td>&lt;80 vs. ≥80</td>
<td>2.13 (1.18–3.85)</td>
<td>0.012</td>
</tr>
<tr>
<td>Blood cell parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemoglobin (g/dL)</td>
<td>&lt;11 vs. ≥11</td>
<td>2.09 (1.18–3.69)</td>
<td>0.011</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>&lt;40 vs. ≥40</td>
<td>1.58 (0.86–2.89)</td>
<td>0.138</td>
</tr>
<tr>
<td>Red blood cells (×10^9/L)</td>
<td>&lt;4 vs. ≥4</td>
<td>1.50 (0.89–2.52)</td>
<td>0.128</td>
</tr>
<tr>
<td>Platelets (×10^9/L)</td>
<td>&lt;100 vs. ≥100</td>
<td>7.60 (1.55–37.35)</td>
<td>0.012</td>
</tr>
<tr>
<td>Platelets (×10^9/L)</td>
<td>&lt;150 vs. ≥150</td>
<td>3.54 (1.77–7.10)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>White blood cells (×10^9/L)</td>
<td>&gt;10 vs. ≤10</td>
<td>1.86 (1.04–3.33)</td>
<td>0.036</td>
</tr>
<tr>
<td>Neutrophils (×10^9/L)</td>
<td>&gt;7 vs. ≤7</td>
<td>2.43 (1.42–4.18)</td>
<td>0.001</td>
</tr>
<tr>
<td>Lymphocytes (×10^9/L)</td>
<td>&lt;1.5 vs. ≥1.5</td>
<td>3.37 (1.58–7.21)</td>
<td>0.002</td>
</tr>
<tr>
<td>Lymphocytes (×10^9/L)</td>
<td>&lt;1 vs. ≥1</td>
<td>2.49 (1.48–4.20)</td>
<td>0.001</td>
</tr>
<tr>
<td>Monocytes (×10^9/L)</td>
<td>&gt;1 vs. ≤1</td>
<td>0.84 (0.35–1.99)</td>
<td>0.687</td>
</tr>
<tr>
<td>Eosinophils (×10^9/L)</td>
<td>&gt;0.07 vs. ≤0.07</td>
<td>0.56 (0.30–1.03)</td>
<td>0.060</td>
</tr>
<tr>
<td>Basophils (×10^9/L)</td>
<td>&gt;0.01 vs. ≤0.01</td>
<td>0.69 (0.41–1.16)</td>
<td>0.160</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; DIC, disseminated intravascular coagulation; ISTH, International Society on Thrombosis and Haemostasis; PT, prothrombin time.

Note: Values are odds ratio and 95% confidence intervals.

aAssuming COVID-19 is associated with DIC, therefore a +2 term was added for all participants.

bAge-adapted threshold for D-dimers: >500 for patients under 60 years, >600 for age 60–69, >700 for age 70–79, >800 for age 80–89, and >900 for age 90–99.
Hematological Predictors for Disease Worsening

Increase of fibrinogen (OR = 9.50, 95% CI: 2.23–40.54) and D-dimers levels (OR = 7.65, 95% CI: 2.67–21.87), a platelet count lower than $100 \times 10^9/\text{L}$ (OR = 7.60, 95% CI: 1.55–37.35), and a positive compensated DIC-ISTH score (OR = 4.58, 95% CI: 2.09–10.07) were major determinants of disease worsening risk. Deficiency of AT activity (OR = 2.13, 95% CI: 1.18–3.85), PT prolongation (OR = 2.43, 95% CI: 1.15–5.13), leukocytosis (OR = 1.86, 95% CI: 1.04–3.33), and lymphopenia with lymphocyte count lower than $1.5 \times 10^9/\text{L}$ (OR = 3.37, CI: 1.58–7.21) were significant risk factors for worsening disease (Table 3).

COMPASS-COVID-19 Score

A multivariate logistic regression analysis led to the derivation of a risk assessment model (RAM) for the identification of COVID-19 patients at high risk for worsening disease. The multivariate analysis retained obesity (BMI $\geq 30$; OR = 6.56, 95% CI: 2.98–14.46; $p < 0.001$), male gender (OR = 2.59, 95% CI: 1.29–5.21; $p = 0.007$), compensated DIC-ISTH score $\geq 5$ (OR = 2.58, 95% CI: 1.07–6.21; $p = 0.034$), lymphocyte count $< 1 \times 10^9/\text{L}$ (OR = 2.21, 95% CI: 1.17–4.19; $p = 0.015$), and Hb $< 11$ g/dL (OR = 2.25, 95% CI: 1.13–4.48; $p = 0.021$) as significant predictors of worsening disease. Multivariate logistic regression analysis led to the following equation:

$$\text{log} \text{ (odds for worsening disease)} = -2.6 + 1.9 \times \text{(obesity)} + 1.0 \times \text{(male gender)} + 0.9 \times \text{(DIC-ISTH score} \geq 5) + 0.8 \times \text{(lymphocytes} \times 10^9/\text{L}) + 0.8 \times \text{(Hb < 11 g/dL)}.$$

The COMPASS-COVID-19 RAM was formulated by calculating an integer numeric value for each predictor according to the value of its multiple regression coefficients (Table 4). The score ranged between 0 and 54 points with a cut-off at 18 points and stratified COVID-19 patients into high and low risk for worsening disease. The COMPASS-COVID-19 score calculated for worsening disease in COVID-19 patients is shown in Table 5.

Table 3 Simplified profile of patients with COVID-19 at high or low risk for disease worsening according to the COMPASS-COVID-19 risk assessment model

<table>
<thead>
<tr>
<th>Patients with COVID-19 at high risk for disease worsening (COMPASS-COVID-19 score $\geq 18$)</th>
<th>Patients with COVID-19 at low risk for disease worsening (COMPASS-COVID-19 score &lt; 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obese (BMI $&gt; 30$), any sex, any examined comorbidities</td>
<td>Nonobese male, compensated DIC-ISTH $&lt; 5$, lymphopenia, anemia$^a$</td>
</tr>
<tr>
<td>Nonobese female with one or more of: compensated DIC-ISTH $\geq 5$, lymphopenia, anemia$^a$</td>
<td>Nonobese female with all three of: compensated DIC-ISTH $\geq 5$, lymphopenia and anemia$^a$</td>
</tr>
<tr>
<td>Nonobese male, compensated DIC-ISTH $&lt; 5$, without lymphopenia, without anemia</td>
<td>Nonobese female with none, one, or two of: compensated DIC-ISTH $\geq 5$, lymphopenia, anemia</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; DIC, disseminated intravascular coagulation; ISTH, International Society on Thrombosis and Haemostasis.

Table 4 COMPASS-COVID-19 score for the evaluation of the risk for worsening disease in COVID-19 patients

<table>
<thead>
<tr>
<th>COMPASS-COVID-19 RAM</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obesity (BMI $&gt; 30$)</td>
<td>19</td>
</tr>
<tr>
<td>Male gender</td>
<td>10</td>
</tr>
<tr>
<td>Compensated DIC-ISTH score $\geq 5$</td>
<td>9</td>
</tr>
<tr>
<td>Confirmed COVID-19</td>
<td>2</td>
</tr>
<tr>
<td>Thrombocytopenia (platelets $&lt; 100,000/\text{µL}$)</td>
<td>1</td>
</tr>
<tr>
<td>Prothrombin time prolongation (&gt; control $+ 3 \text{ s}$)</td>
<td>1</td>
</tr>
<tr>
<td>D-dimer increase (&gt;500 for age $&lt; 60 \text{ y}$; &gt;600 ng/mL for age 60–79 y; &gt;800 ng/mL for age $80–89 \text{ y}$; &gt;900 ng/mL for age 90–99 y)</td>
<td>1</td>
</tr>
<tr>
<td>Antithrombin decrease ( &lt; lower normal limit established by the laboratory)</td>
<td>1</td>
</tr>
<tr>
<td>Protein C decrease (&lt; lower normal limit established by the laboratory)</td>
<td>1</td>
</tr>
<tr>
<td>Total $\geq 5$</td>
<td></td>
</tr>
<tr>
<td>Lymphocytes $&lt; 10^9/\text{L}$</td>
<td>8</td>
</tr>
<tr>
<td>Hemoglobin $&lt; 11 \text{ g/dL}$</td>
<td>8</td>
</tr>
<tr>
<td>Total $\geq 18$: high risk $&lt; 18$: low risk</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; DIC, disseminated intravascular coagulation; ISTH, International Society on Thrombosis and Haemostasis.
nonworsening cases (the ROC analysis of the model (area under the curve)
parameters such as obesity, gender, lymphocyte count, and
univariate model based on the DIC-ISTH score (AIC
all other examined logistic regression models, including a
with the score minimized the AIC (AIC
good discrimination capacity (AUC
38% of the patients at the G-group. The sensitivity and the
the observed number of patients whose condition did not
Pearson’s $r^2 = 0.965$ for worsening cases and $r^2 = 0.992$ for
of the score (through the logistic regression equation underlying the score) versus observed probability in
in worsening cases (circles) and nonworsening cases (triangles). Frame B: the ROC analysis of the model (area under the curve = 0.77).

Fig. 1 Qualitative characteristics of the COMPASS-COVID-19 score. Frame A: plot presenting the expected (through the logistic regression equation underlying the score) versus observed probability in worsening cases (circles) and nonworsening cases (triangles). Frame B: the ROC analysis of the model (area under the curve = 0.77).

Validation of the COMPASS-COVID-19 Score
Patients included in the validation cohort were prospectively
hemoglobin levels, adopted in the COMPASS-COVID-19 score.

Discussion
Development of prognostic tools and biomarkers for the
prediction of COVID-19 trajectory from the time of symptom
onset is a difficult task needing urgent response. To
anticipate this challenge, we performed this prospective
observational cohort study which led to the derivation and
validation of the COMPASS-COVID-19 RAM.

We showed that in COVID-19 patients disease worsening
is related to the presence of cardiovascular risk factors (i.e.,
arterial hypertension, diabetes, and obesity) and blood
hypercoagulability. The present study showed for the first
time that compensated DIC, diagnosed according to the ISTH
criteria, was already present in 8 and 28% of COVID-19
patients when admitted at the medical conventional ward and
the ICU, respectively. Thus, compensated DIC is an
independent risk factor for disease worsening. This figure
completes the substantial role of blood coagulation activation
and DIC in the poor prognosis of COVID-19 patients.

Our study underlines that COVID-19 is associated with
enhanced blood hypercoagulability documented by the
consumption of natural coagulation inhibitors (particularly AT)
and the marked increase of D-dimers. This concept is further
supported by data from recent postmortem analysis in
COVID-19 patients that showed endothelial cell activation
and microcirculation abnormalities implicating blood hyper-
coagulability in the process of disease aggravation.
Consequently, our data justify the monitoring of hypercoag-
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antithrombotic treatment in COVID-19 patients. Moreover,
close monitoring of AT levels—the most potent heparin cofactor—and its administration in the case of deficiency is
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Our study led to the derivation of the COMPASS-COVID-19
score which includes the following easily assessable predic-
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hematological predictors of the score can be easily measured
in nonspecialized hematological laboratories. This score is
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hematological laboratory. At the cut-off of 18 points, the score
has a very good discriminating capacity to stratify patients at
high and low risks for disease aggravation, with an AUC value of
0.77, a sensitivity of 81%, and a specificity of 60%. These
qualitative characteristics together with the feasibility of
measuring routine hematological parameters designate the
COMPASS–COVID-19 score as a useful clinical tool, promptly
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at high risk for disease worsening and as requiring an opti-

specificity of the score were 94 and 58% respectively and the
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The COMPASS-COVID-19 score for the prediction of disease worsening in hospitalized patients was developed according to the TRIPOD reporting guidelines. Data analysis was performed taking into consideration the major conclusions of the systematic review and critical appraisal of prediction models for diagnosis and prognosis of COVID-19 infection published by Wynants et al. The prospective design of our study is a strength for the derivation of the new RAM since all patients were tested with the COAG-COVID panel which provided information on hematological alterations together with specific evaluation of biomarkers of hypercoagulability. Moreover, this design allowed the evaluation of the presence of compensated DIC on the first hospitalization day of patients either at the conventional COVID-19 medical ward or at the ICU. The COMPASS-COVID-19 score is not applicable in patients receiving anticoagulant treatment with direct oral anticoagulants or vitamin K antagonists because these antithrombotic agents introduce prolongation of PT. Moreover, treatment with direct oral anticoagulants (DOACs) induces a variable degree of overestimation of PC activity when a clotting based assay is used. However, the low number of patients with COVID-19 on anticoagulant treatment admitted in our center did not allow the evaluation of the abovementioned conditions on the accuracy of the COMPASS-COVID-19 score. This is an issue that has to be evaluated in the external validation of the score.

Time to event analysis is considered to be the optimal methodology for the elaboration of predictive scores allowing for administrative censoring in a competing risk framework. However, this strategy was practically unfeasible during the actual phase of the pandemic, which had an extreme pressure on our hospital and on the availability of ICU beds in the city of Paris. For this reason, the cohort design was selected.

External validation is the optimal strategy to control the accuracy of predictive models. However, in the actual phase of the pandemic, this validation strategy is practically impossible to apply. For this reason, we set up an independent validation cohort of patients selected from new patients hospitalized at the COVID-16 center at Tenon University hospital between April 6 and April 21. The assessment of patients enrolled in the validation cohort showed that the COMPASS-COVID-19 score accurately predicted patients at high risk for disease worsening with a very high sensitivity reaching up to 96%. An independent multicenter external validation of the COMPASS-COVID-19 score is ongoing.

Demographics and epidemiological characteristics of the patients enrolled in our study were similar to those described in recently published studies from United States and China. Moreover, the low frequency of active smokers found in our cohorts was also reported in recent studies. These similarities further support that patients enrolled in our cohorts are representative of those suffering from COVID-19 in the community and support the generalizability of our findings. Moreover, very limited exclusion criteria were applied, yielding our cohort representative of the population of COVID-19 patients requiring hospitalization. These characteristics of our study allow implementation of the COMPASS-COVID-19 score across different settings and populations.

We aimed to derive an original, simple, and easy-to-use RAM based on clinical predictors and concrete hematological parameters closely related to mechanisms implicated in COVID-19 pathogenesis. Indeed, available evidence so far has reinforced the importance of blood coagulation, endothelial cell activation, white blood cell alterations, and hypoxia in the deterioration of COVID-19 patients. An enhanced inflammatory reaction with associated cytokine storm has a central role in COVID-19 patients’ worsening. This has also been extensively described in the analysis of biochemical biomarkers of inflammation such as ferritin. Nevertheless, the inflammatory process is reflected upon some of the hematological parameters studied, such as fibrinogen levels, platelets, and white blood cell counts. To the best of our knowledge, two studies have been published to date aiming to elaborate a prediction tool for disease severity in patients hospitalized with COVID-19 and are based on the evaluation of biochemical biomarkers. Both studies included very limited numbers of patients, which hardly allowed (if so) sufficient statistical power to identify score predictors by applying the rule-of-thumb (the so-called EPV 10–1) method for predictive score derivation. In contrast, the COMPASS-COVID-19 score derived from a robust cohort with a sufficient number of patients in the two groups allowing accurate identification of the most pertinent biological and clinical predictors by following the above-mentioned rule.

Despite its original nature, this study bears some limitations. First, in our approach, an unweighted Youden’s index was used to establish the optimal cut-off in the score, allocating equal importance to sensitivity and specificity, and yielding a sensitivity of 81% and a specificity of 60%; alternative, weighted approaches prioritizing for instance sensitivity over specificity could lead to other cut-off values. Another limitation pertains to the number of patients and the single-center design of the study as well as the short admission time, which were imposed by the urgent character of the SARS-CoV-2 epidemic.

Regarding the external validity and generalizability of findings, it should be underlined that the COMPASS-COVID-19 score is applicable in patients receiving heparin treatment since all patients hospitalized in a conventional medical department or in an ICU routinely receive thromboprophylaxis with body weight-adapted enoxaparin as in our setting. At the actual phase of the score development, the score is not applicable to pregnant women, patients on anticoagulant treatment with VKA or DOAC, and patients with cytopenia due to current anticancer treatment, since these groups of patients were excluded from this study. The applicability of the score on these special groups of patients will be explored in the forthcoming studies.

In conclusion, the present study provides an accurate RAM for early identification of patients with COVID-19 being at high risk of disease worsening that responds to the criteria established by the TRIPOD guidelines. Contextualized application of the COMPASS-COVID-19 score will provide a useful
What is known about this topic?

- Development of prognostic tools for the prediction of COVID-19 trajectory from the time of symptom onset is recommended by expert consensus.

What does this paper add?

- The COMPASS-COVID-19 score derived from a prospective study is composed of easily assessable clinical and hematological predictors.
- The COMPASS-COVID-19 score has high sensitivity (81%) for the identification of hospitalized patients at high risk of disease worsening.

References

3. Terpos E, Ntanasis-Stathopoulos I, Elalamy I, et al. Hematological and blood coagulation biomarkers, and it can be applied at any level of the health care system. Implementation of the COMPASS-COVID-19 score will allow an easy and rapid identification of a great majority of COVID-19 patients at risk for disease worsening and who may shortly require ICU admission.

Conflict of Interest
None declared.