1. Technical Details Regarding Model Training using Nested Cross Validation

The training and validation procedures are summarized in Figure S1. Nested five-fold cross validation was carried out, with outer and inner CV loops. The outer CV loop is used to obtain the performance on the development cohort for concurrent validation. For the outer CV loop, the development cohort was split into five folds containing distinct subsets of patients. For each loop, one fold was held out for testing, while the other four were used for training. Repeating this 5 times, and concatenating predictions from each of the resulting five independent models, we get estimate performance on the development cohort. For each external CV loop, an inner CV loop is used to choose the optimal value of model hyperparameter, i.e. the strength of the LASSO penalty (lambda) that maximizes the F1 score across 5 folds of internal CV

In both outer and inner CV loop, prior to model training, we standardized each predictor in the training set by subtracting its mean and dividing its standard deviation (SD) (z-score) across the training set. The testing set was standardized in the same way, using means and SDs computed on the development cohort.

After CV, a final model with hyperparameters that are one-level stronger than the most common hyperparameter among the five independent models was fit on the entire development cohort. This final model was the one tested on the prospective cohort, after standardization using the means and SDs from the development cohort.

The LTR model yields probabilities for each potential adverse event occurring within the next 7 days. These are used to create acuity scores by taking the expected outcome value (weighted sum of the ordinal
adverse event outcome values (0, 1, 2, and 3) with weights equal to the event probabilities). The acuity values are finally rescaled for ease of interpretation to the range 0 (minimum acuity) to 100 (maximum acuity). For a given acuity score, CoVAS provides a predicted probability of each adverse outcome. These predicted probabilities are obtained by ordinal Platt calibration\(^4\), meaning that we fit an ordered logit model with the CoVAS acuity score as a single input, to provide probabilities for hospitalization, critical illness (need for ICU care or MV), or death. Platt calibrated probabilities are used instead of directly using the original model probabilities used in the acuity scores because, empirically, the original probabilities are not well calibrated.

2. Predictor encoding conventions

For predictors that are binary, we use the following encoding:
- encode 1 = present or positive;
- -1 = absent or negative;
- 0 = unavailable or no record of testing.

For smoking status, we used 0 = never or passive; and 1 = yes or quit.

3. Details of computing CoVA Scores and Risk Predictions

The following is a set of instructions for anyone wishing to write a computer program that calculates the CoVA score (e.g. in an electronic medical record).

The mean, std, and coef values are provided in Table S1 (see below).

1. Define input features
   - If no chest X-ray is available, set to 0; otherwise, pattern present = 1, no pattern = -1.
   - If no COVID status available, set to 0; otherwise, test positive = 1, negative = -1.

2. z-score standardization: subtract the mean, divide by the standard deviation for each feature, 
   \[ x_i \leftarrow \frac{(x_i - \text{mean}_i)}{\text{std}_i} \]

3. Compute z (a number for each patient)
   \[ z = \beta_0 + \beta_1 x_1 + \ldots + \beta_K x_K \]

4. Compute yhat (a 4-element probability distribution for each patient)
   \[ \text{yhat} = [\exp(-z_{-\text{none}}^2) / M, \exp(-z_{\text{hosp}}^2) / M, \exp(-z_{\text{icu_intub}}^2) / M, \exp(-z_{\text{death}}^2) / M] \]
   where \( M = \exp(-z_{-\text{none}}^2) + \exp(-z_{\text{hosp}}^2) + \exp(-z_{\text{icu_intub}}^2) + \exp(-z_{\text{death}}^2) \)
   - \( \mu_{\text{none}} = -0.7138; \)
   - \( \mu_{\text{hosp}} = 0.5514; \)
   - \( \mu_{\text{icu_intub}} = 1.1932; \)
   - \( \mu_{\text{death}} = 2.6278. \)

5. Compute acuity score, a, which the expectation of yhat
\[ a = E[yhat] = 0*yhat\_none + 1*yhat\_hosp + 2*yhat\_icu\_intub + 3*yhat\_death \]

where
\begin{align*}
    yhat\_none & \text{ is the 1st element in yhat;} \\
    yhat\_hosp & \text{ is the 1st element in yhat;} \\
    yhat\_icu\_intub & \text{ is the 1st element in yhat; and} \\
    yhat\_death & \text{ is the 1st element in yhat.}
\end{align*}

Note: For display, we rescale the acuity score to the range 0-100. This is done by scaling the acuity score, \(a\), to obtain a new score, \(A = 100*a/3\).

6. Recalibration: compute the predicted distribution (yp) based on the acuity score

\[ \begin{align*}
    \text{tmp0} &= 0 \\
    \text{tmp1} &= \text{sigmoid}(1.7836 - 1.4130*\text{acuity score}) \\
    \text{tmp2} &= \text{sigmoid}(4.1649 - 1.4130*\text{acuity score}) \\
    \text{tmp3} &= \text{sigmoid}(6.4918 - 1.4130*\text{acuity score}) \\
    \text{tmp4} &= 1
\end{align*} \]

where \(\text{sigmoid}(x) = 1/(1+\exp(-x))\)

\[ \begin{align*}
    P(\text{none}) &= (\text{tmp1}\_\text{-tmp0})\*100\% \\
    P(\text{hosp}) &= (\text{tmp2}\_\text{-tmp1})\*100\% \\
    P(\text{icu\_intub}) &= (\text{tmp3}\_\text{-tmp2})\*100\% \\
    P(\text{death}) &= (\text{tmp4}\_\text{-tmp3})\*100\%
\end{align*} \]

Finally, \(yp = [P(\text{none}), P(\text{hosp}), P(\text{icu\_intub}), P(\text{death})]\)
Table S1: Model parameter values. Values used for z-normalization (mean, std) and CoVA model coefficients.

| Predictor                              | Mean   | Std    | beta  |
|----------------------------------------|--------|--------|-------|
| Age                                    | 51.07594 | 19.22809 | 0.7353 |
| Sex                                    | 0.51103 | 0.49988 | 0.08078 |
| Respiratory Rate                       | 18.80844 | 3.1239 | 0.27459 |
| Heart Rate                             | 81.13687 | 14.76491 | 0.12154 |
| Temperature                            | 98.13069 | 0.9537 | 0.1206 |
| CCI                                    | 1.46552 | 2.41655 | 0.11423 |
| BMI_high (>35kg/m2)                    | 0.03475 | 0.18315 | 0.00284 |
| BMI_low (<18.5kg/m2)                   | 0.00917 | 0.09531 | -0.00014 |
| SpO2                                   | 97.26989 | 2.24487 | -0.37759 |
| Diastolic blood pressure               | 73.29219 | 12.25362 | -0.47241 |
| Systolic blood pressure                | 130.36659 | 20.1278 | -0.11512 |
| Ais_hx                                 | 0.05916 | 0.23593 | 0.17463 |
| Ich_hx                                 | 0.0081 | 0.08964 | 0.10869 |
| Sah_hx                                 | 0.00586 | 0.07634 | 0.09191 |
| Hem-cx_hx                             | 0.02089 | 0.14303 | 0.07649 |
| Renal-cx_hx                           | 0.0177 | 0.13184 | 0.0681 |
| Pancreatitis_hx                       | 0.01514 | 0.1221 | 0.0608 |
| Cf_hx                                 | 0.00107 | 0.03263 | 0.04917 |
| Arrest_hx                             | 0.0032 | 0.05646 | 0.04914 |
| Seizure_hx                            | 0.02185 | 0.1462 | 0.04369 |
| Als_hx                                | 0.00128 | 0.03574 | 0.04054 |
| M-acid_hx                             | 0.01546 | 0.12336 | 0.03845 |
| Mg_hx                                 | 0.00181 | 0.04253 | 0.03735 |
| Pneumothorax_hx                       | 0.00149 | 0.0386 | 0.03003 |
| Sma_hx                                | 0.00171 | 0.04126 | 0.02414 |
| Pericarditis_hx                       | 0.00842 | 0.09138 | 0.01441 |
| ARDS_hx                               | 0.00693 | 0.08295 | 0.00011 |
| ever_positive_upToEvent               | 0      | 1      | 0.275  |
| cxr_Multifocal                        | 0      | 1      | 0.12929 |
| cxr_TypicalPatternForCovid            | 0      | 1      | 0.00014 |
| beta0                                 |        |        | -0.09257 |
### Table S2. Prior risk predictions models for COVID-19.

This table summarizes relevant studies reviewed in “Prediction models for diagnosis and prognosis of covid-19: systematic review and critical appraisal”, BMJ 2020; 369 doi: [https://doi.org/10.1136/bmj.m1328](https://doi.org/10.1136/bmj.m1328), 07 April 2020 and BMJ 2020;369:m2204, [https://www.bmj.com/content/369/bmj.m2204](https://www.bmj.com/content/369/bmj.m2204), reviewed on June 10, 2020.

| Study/location          | Population                | Outcome                                                   | Predictors                                                                 | Sample size for model development | Type of model | Validation method | Sample size for Validation | Performance  |
|-------------------------|---------------------------|-----------------------------------------------------------|----------------------------------------------------------------------------|-----------------------------------|---------------|------------------|---------------------------|--------------|
| Decaprio et al[1],     | General Population        | Complications from pneumonia (proxy events, not COVID-19) | Age, sex, previous hospital admissions, diagnostic features, interaction terms | ~1.5 million                     | LR XGB        | Training test split | 369,865                   | AUC: LR 0.73 XGB: 0.81 |
| United States, [Preprint] |                           |                                                           |                                                                            |                                   |               |                  |                           |              |
| Bai et al[2], China,   | Inpatients, covid+        | severe disease                                            | Clinical variables, lab values, chest CT features                         | 133 (54)                          | LSTM + MLP    | Unclear          | N/A                       | AUC 0.95       |
| [preprint]              |                           |                                                           |                                                                            |                                   |               |                  |                           |              |
| Gong et al[3], China,  | Inpatients COVID-19+      | severe disease within 15 days                              | Clinical variables, lab values                                            | 189 (28)                          | LR+ LASSO, RF, DT, SVM | External validation | Two external validation sites 165 (40) and 18 (4) | AUC 0.85     |
| [Preprint]              |                           |                                                           |                                                                            |                                   |               |                  |                           |              |
| Qi et al[4] China       | Inpatients, COVID-19+     | hospital stay >10 days features from CT images             |                                                                            | 26 (20)                           | LR RF         | 5 fold cross validation | N/A                       | AUC; LR 0.92 RF: 0.96 |
| Shi et al[5] China      | Inpatients COVID-19+      | Death or severe COVID-19                                   | Age, sex, HTN                                                              | 487 (49)                          | LR            | Validation in less severe | 66(15)                     | Not reported  |
| Xie et al[6] China      | Inpatients COVID-19+      | mortality                                                  | Age, LDH, lymphocyte count, SpO2                                           | 299(155)                          | LR            | External Validation   | 145 (69)                   | AUC: 0.98     |
| [preprint]              |                           |                                                           |                                                                            |                                   |               |                  |                           |              |
| Yan et al[7], China     | Inpatients Suspected COVID-19+ | mortality                                            | LDH, lymphocyte, hs-CRP                                                   | 375 (174)                         | XGB           | Prospective validation | 29 (17)                    | Sensitivity 92 PPV 95 |
| Yuan et al[8] China     | Inpatients COVID-19+      | mortality                                                  | CT imaging score                                                           | 27 (10)                           | N/a           | Na/a             | N/a                       | AUC: 0.90     |
| Huang et al[9] China    | Inpatients COVID-19+      | severe disease progression                                 | comorbidities, RR, CRP, LDH                                               | 125(32)                           | LR            | N/a              | AUC: 0.99                  |              |
| [preprint]              |                           |                                                           |                                                                            |                                   |               |                  |                           |              |
| Name          | Country          | Inpatients | COVID-19+ | LOS | CT features | Severity | CT and labs | Labs | SVM, ANN, RF, DT, LR, KNN | Cross validation | AUC    |
|---------------|------------------|------------|----------|-----|-------------|----------|-------------|------|--------------------------|-----------------|--------|
| Pourhomayoun  | Multiple countries | Inpatients COVID-19+ | mortality | Not defined | 117,000 | 10 fold cross validation | n/a | AUC: 0.96 |
| Sarkar        | Multiple countries | Inpatients with COVID symptoms | mortality | Age, days of symptoms prior to admission, travel or from Wuhan | 115(37) | RF | N/a | N/a | AUC: 0.97 |
| Wang          | China | Inpatient COVID 19+ | LOS | CT features | 485 | DL | External validation | 290 | AUC 0.81 |
| Zeng          | China | Inpatients COVID-19+ | Severe disease progression | CT and labs | 338(76) | Multivariate survival analysis | Cross validation | AUC: 0.88 |

Legend: LR = logistic regression; RF = random forest; DT = decision tree; MLP = multilayer perceptron; SVM = support vector machine; LASSO = least absolute shrinkage and selection operator (aks L1 regularization); XGB = XGboost, aka gradient boosted decision trees; Covid+ = tested positive for Covid-19; LOS= length of hospital stay

REFERENCES

1. DeCaprio D, Gartner J, Burgess T, Kothari S, Sayed S. Building a COVID-19 vulnerability index. arXiv preprint arXiv:200307347 2020;

2. Bai X, Fang C, Zhou Y, et al. Predicting COVID-19 malignant progression with AI techniques. 2020;

3. Gong J, Ou J, Qiu X, et al. A Tool to Early Predict Severe 2019-Novel Coronavirus Pneumonia (COVID-19) : A Multicenter Study using the Risk Nomogram in Wuhan and Guangdong, China. medRxiv 2020; :2020.03.17.20037515.

4. Qi X, Jiang Z, Yu Q, et al. Machine learning-based CT radiomics model for predicting hospital stay in patients with pneumonia associated with SARS-CoV-2 infection: A multicenter study. medRxiv 2020; :2020.02.29.20029603.

5. Shi Y, Yu X, Zhao H, Wang H, Zhao R, Sheng J. Host susceptibility to severe COVID-19 and establishment of a host risk score: findings of 487 cases outside Wuhan. Critical Care 2020; 24:1–4.

6. Xie J, Hungerford D, Chen H, et al. Development and external validation of a prognostic multivariable model on admission for hospitalized patients with COVID-19. 2020;

7. Yan L, Zhang H-T, Goncalves J, et al. A machine learning-based model for survival prediction in patients with severe COVID-19 infection. MedRxiv 2020;

8. Yuan M, Yin W, Tao Z, Tan W, Hu Y. Association of radiologic findings with mortality of patients infected with 2019 novel coronavirus in Wuhan, China. Plos one 2020; 15:e0230548.

9. Huang H, Cai S, Li Y, et al. Prognostic factors for COVID-19 pneumonia progression to severe symptom based on the earlier clinical features: a retrospective analysis. medRxiv 2020;
10. Pourhomayoun M, Shakibi M. Predicting mortality risk in patients with COVID-19 using artificial intelligence to help medical decision-making. medRxiv 2020;

11. Sarkar J, Chakrabarti P. A Machine Learning Model Reveals Older Age and Delayed Hospitalization as Predictors of Mortality in Patients with COVID-19. medRxiv 2020;

12. Wang S, Zha Y, Li W, et al. A fully automatic deep learning system for COVID-19 diagnostic and prognostic analysis. European Respiratory Journal 2020;

13. Zeng L, Li J, Liao M, et al. Risk assessment of progression to severe conditions for patients with COVID-19 pneumonia: a single-center retrospective study. medRxiv 2020;

Table S3. ICD codes used to define the diagnoses

| Predictor category | Abbreviation | Predictor | ICD-10 codes |
|--------------------|--------------|-----------|--------------|
| Demographics       | Age          | Age       | N/A          |
|                    | BMI          | BMI       | N/A          |
|                    | covid-test   | COVID-19 testing status | N/A |
| Smoking            | Smoking      | Smoking   | F17.201, F17.208, F17.203, F17.209, F17.210, F17.200, F17.218, F17.291, F17.299, F17.298, Z72.0, Z87.891, O99.334, O99.335, O99.330, K03.6, T65,291 |
| Vital signs        | VS           | Systolic blood pressure, Diastolic blood pressure, Temperature, Heart rate, Respiratory Rate, Oxygen saturation (SpO2) | N/A |
| Symptoms           | Anosmia      | Anosmia   | R43.0, R43.8, R43.9 |
|                    | Dysgeusia    | Dysgeusia | R43.2 |
| Infectious         | Hiv          | Human immunodeficiency virus infection (HIV) | B20, Z21, O98.71 |
| Pulmonary | Ards | Acute respiratory distress syndrome - acute | J80 |
|-----------|-----|------------------------------------------|-----|
| Ards-hx*  |     | Acute respiratory distress syndrome      | Z87.09 |
| Asthma    |     | Asthma                                   | J45.51, J45.40, J45.41, J45.42, J45.30, J45.31, J45.32, J45.20, J45.52, J45.22, J45.20, J45.909, J45.902, J44.9, J44.1 |
| Bronchitis|     | Bronchitis                               | J40, J41, J41.0, J41.1, J41.8, J42 |
| COPD      |     | Chronic obstructive pulmonary disease    | J44.9, J98.8 |
| Cf        |     | Cystic fibrosis                          | E84.9 |
| Copd      |     | Chronic obstructive pulmonary disease    | J44.9, J44.1, J44.0, J44.9 |
| Ild       |     | Interstitial lung disease                | J81, J82, J84, J84.0, J84.1, J84.8, J84.9 |
| Pe        |     | Pulmonary embolism                       | I26, I26.0, I26.9 |
| Pneumonia |     | Pneumonia                                | A01.03, A02.22, A37.01, A37.11, A37.81, A37.91, A48.1, A50.04, A54.84, B05.2, B06.81, B77.81, J09.X1, J10.0, J10.00, J10.01, J10.08, J11.0, J11.00, J11.08, J12.1, J12.2, J12.3, J12.8, J12.81, J12.89, J13, J14, J15.0, J15.1, J15.2, J15.20, J15.21, J15.211, J15.212, J15.29, J15.3, J15.4, J15.5, J15.7, J15.8, J15.9, J16, J16.0, J16.8, J18.0, J18.1, J18.2, J18.8, J84.11, J84.116, J12.0, J82, A22.1, J69.0, J12.9, J69.1, J69.8, J95.4, J18.9, J84.89, J68.0, J15.6, J18.89, J95.851, B01.2, A21.2, J15.29, |
| Condition                      | ICD-10 Codes                       |
|-------------------------------|-----------------------------------|
| Pneumothorax                  | J93.0, J95.811, J93.9, J93.83     |
| Cardiovascular Arrest         | I46, I46.0, I46.1, I46.9          |
| Arrythmia                     | I48, I49, I49.0, I49.1, I49.2, I49.3, I49.4, I49.5, I49.8, I49.9 |
| CM                            | I42, I42.0, I42.1, I42.2, I42.3, I42.4, I42.5, I42.6, I42.7, I42.8, I42.9, I43, I43.0, I43.1, I43.2, I43.8 |
| Cad                           | I24.0, I24.1, I24.9, I24, I25.10, I25.9, I25.810, I25.812, I25.719, I25.729, I25.721, I25.730, I25.750, I25.751, I25.739, I25.760, I25.700, I25.709, I25.720, I25.759, I25.41, I25.42, I25.710, I25.711, I25.701, I25.761, I25.731, I25.769, I25.75, I25.701, I25.799, I25.728, I25.791, I25.798, I25.110, I25.111, I25.119, I25.118, I21.09, I21.19, I21.29, I21.4, I21.9 |
| Cad-hx                        | Z95.1, Z98.61, Z95.5, Z86.79      |
| Chf                           | I50.32, I50.33, I50.31, I50.20, I50.40, I50.9, I50.30, I50.1, I50.23, I50.22, I50.43, I50.21, I50.41, I50.9, I11.0, I50, I50.0, I50.1, I50.9 |
| Chf-hx                        | Z82.49                            |
| Code  | Description                     | ICD-10 Codes                     |
|-------|---------------------------------|----------------------------------|
| Dm    | Diabetes                        | E11.9, E10.9, E13.9, E11.69, E09.9, E11.69, E11.10, E11.01, E11.39, E10.10, E10.69, E10.65, E10.49, E11.49, E10.29, E11.29, E10.29, E10.51, E11.51, E11.8, E10.8, E11.40, E10.40, E11.41, E10.41, E10.641, E11.21, E11.39 |
| Htn   | Hypertension - acute            | I10, I11.9, I11.0, I12.9, I12.0, I13.10, I13.0, I13.11, I13.2, I15.2, I15.8, I15.0, G93.2, I15.0, I15.9, I10.02, I97.3, I15.1, I15.2 |
| Htn-hx| Hypertension                    | Z86.79                           |
| Htn-obs| Hypertension - obs             | O10.419, O10.42, O10.43, O10.419, O10.93, O10.919, O13.9, O13.5, O16.9, O16.5, O16.9, O10.119, O10919, O10.92, O10.319, O10.119, O10.219, O10.419, O10.23, O13.9, O10.03, O13.5, O16.9, O16.5, O10.019 |
| Mi    | Myocardial infarction           | I21, I22                         |
| Myocarditis | Myocarditis                  | I40, I40.0, I40.1, I40.8, I40.9, I41, I41.0, I41.1, I41.2, I41.8 |
| Obesity| Obesity                        | E66.9, E66.01, E66.8, E66.1, E66.01 |
| Ow    | Obesity                         | E66.3                            |
| Pvd   | Peripheral vascular disease     | I73, I73.0, I73.00, I73.01, I73.1, I73.8, I73.81, I73.89, I73.9 |
| Renal | Aki                             | N17.9                            |
| Ckd-end| Chronic kidney disease - end stage | N18.5, N18.6, Z99.2             |
| Ckd-iv| Chronic kidney disease - Stage IV | N18.1, N18.2, N18.3, N18.4       |
| Renal-cx | Renal cancer | C34.90, C34.91, C34.92, C78.01, C64.9, C64.21, C68.2, C66.1, C34.91, C64.9 |
|----------|--------------|------------------------------------------------------------------|
| **Neurologic** | **Ais** | Ischemic stroke - acute | I63.9, I63.81, I67.9, R27.0, G46.4, I63.232, I63.232, I63.231, I63.512, I63.511, I63.511, I63.522, I63.21, I63.531, I63.532, I63.29, I63.219, I63.22, I63.529, I63.539, I63.9, I63.89, I63.429, I63.12, I63.139, I63.449, I63.40, I63.422, I63.132, I63.442, I63.412, I63.432, I63.112, I63.419, I63.439, I63.10, I63.421, I63.131, I63.441, I63.411, I63.431, I63.111, I63.119, I63.329, I63.02, I63.039, I63.349, I63.30, I63.322, I63.032, I63.342, I63.312, I63.332, I63.012, I63.319, I63.339, I63.321, I63.031, I63.341, I63.311, I63.331, I63.011, I63.019 |
| **Ais-hx** | Ischemic stroke | Z86.73, Z86.69, I69.359, I69.30, I69.391, I69.398, I69.390, I69.393, I69.319, I69.321, i69.359, i69.328, i69.398, i69.349, i69.365, i69.369, i69.398, r20.9 |
| **Als** | Amyolateral Sclerosis | G12.21 |
| **Brain-cx** | Brain malignancy | C71.9, C72.30, C69.22, C69.21, C71.6, C71.1, C71.0, Z85.841 |
| **CIM** | Critical illness myopathy | G72.81 |
| **CIN** | Critical illness neuropathy | G62.81 |
| **Ce** | Cerebral edema | G93.6 |
| **Cmt** | Charcot Marie Tooth Disease | G60.0 |
| **Coma** | Coma - history of | R40.20 |
| **Dementia** | Dementia | G30.9, G30, F02.80, F03.90, G31.09, G30.0, F02.81 |
| **Gbs** | Guillain Barre Syndrome | G61.0 |
| Condition          | Condition          | Code(s)                                                                 |
|--------------------|--------------------|-------------------------------------------------------------------------|
| Hemiplesia         | Hemiplegia         | G81, G81.0, G81.1, G81.9, G82, G82.0, G82.1, G82.2, G83                 |
| Hydrocephalus      | Hydrocephalus      | G91, G91.0, G91.1, G91.2, G91.3, G91.8, G91.9                          |
| Ich                | Intracranial hemorrhage - acute | I62.9, i62.1, I62.00, I61.5, I61.4, S06.300A, S06.309A, S06.305A, S06.2X9A, S06.0XXA, S02.91XA, S02.109A, S02.0XXA, S02.109B, S02.0XXK, S02.109G, S02.0XXD, S02.109D, S02.91XK, S02.91XB, S02.91XA |
| Ich-hx             | Intracranial hemorrhage | I69.293, I69.262, I69.261, I69.220, I69.290, I69.223, I69.26, I69.292, I69.263, I69.362, I69.227, I69.244, I69.241, I69.249, I69.239, I69.2, I69.29, I69.232, I69.25, I69.24, I69.23, I69.21, I69.252, I69.269, I69.254, I69.228, I69.233, I69.242, I69.234, I69.231, I69.243, I69.259 |
| Ih                 | Intracranial hyertension | G93.2                                                                    |
| Inf-men-enc        | Meningitis or encephalitis | A86, A87.2, A87.9, A85.1, A85.2, A87.1, A87.0, Z86.61, A32.11, A17.0, A39.0, A37.00, A69.21, A87.2, A85.8, A83.2, A84.1, A84.8, A83.5, A83.2, G03.8, G03.8, A32.11, A92.39, G00.1, A92.32, A52.13, G00.8, B45.1, G02, A27.81, A51.41, B38.4, G01, B00.3, G00.9, B39.9, B00.4, G03.9, B01.0, B02.1, G08, G03.1, G03.0, B01.11, B06.01, B60.2, B30.8, A07.8, A85.8, J11.81 |
| Mg                 | Myasthenia gravis  | G70.00, G70.01, G70                                                    |
| Movement           | Movement disorder  | G21, G21.0, G21.1, G21.1, G21.3, G21.8, G21.9, G22, G23, G23.0, G23.1, G23.2, G23.8, G23.9, G24, G24.0, G24.1, G24.2, G24.3, G24.4, G24.5, G24.8, G24.9, G25, G25.0, G25.1, G25.2, G25.3, G25.4, G25.5, G25.6, G25.8, G25.9, G26, G10, G11, G11.0, G11.1, G11.2, G11.3, G11.4, G11.8, G11.9, G12, G12.0, G12.1, G12.2, G12.8, G12.9, G13, G13.0, G13.1, G13.2, G13.8 |
| Ms | Multiple sclerosis | G35, G37.9, G37.8, G35, G36, G36.0, G37, G37.9 |
| Neuromuscular | Neuromuscular | G70, G70.0, G70.1, G70.2, G71, G71.0, G71.1, G71.2, G71.3, G71.8, G71.9, G72, G72.0, G72.4, G73, G73.0, G73.1, G73.3, G73.4, G73.5, G73.6, G73.7 |
| Neuropathy | Neuropathy | G60, G60.0, G60.1, G60.2, G60.3, G60.8, G60.9, G61, G61.1, G61.8, G61.9, G62, G62.0, G62.1, G62.2, G62.8, G62.9, G63, G63.1, G63.2, G63.3, G63.4, G63.5, G63.6, G63.8, G64, G50, G50.0, G51.0, G51.0 |
| PbP | Pseudobulbar palsy | G12.22 |
| Pls | Primary lateral sclerosis | G.12.23 |
| Pn | Peripheral neuropathy | G90.0, G90.09, G60.9 |
| Sah | Subarachnoid hemorrhage - acute | I60.9, I60.8, I60.5, I60.00, I60.2, I60.01, I60.02, I60.00, I60.51, I60.52, I60.50, I60.31, I60.32, I60.7, I60.4, I60.10, I60.11, I60.12, I60.31, I60.32, I60.3, I60.30, I60.20, I60.10, I60.6, S06.6X9A, S06.6X0A, S06.6X5A, S01.90XA |
| Sah-hx | Subarachnoid hemorrhage | z86.79, I69.093, I69.021, I69.032, I69.043, I69.039, I69.044, I69.00, I69.020, I69.091, I69.033, I69.041 |
| Sdh | Subdural hematoma - acute | S06.5X9A, S02.0XXA, S02.0XXB, S02.109A, S02.109B, S06.5X9D, S06.5X5A, S06.5X0A, S06.6X9A, S06.4X9A, I62.00 |
| Sdh-hx | Subdural hematoma | Z98.890 |
| Category          | Diagnosis                       | Codes                                                                 |
|------------------|---------------------------------|----------------------------------------------------------------------|
| Seizure          | Seizure / epilepsy              | G40.90, G40.901, G40.909, G40.91, G40.911, G40.919, G40.811, G40.80, G40.801, G40.802, G40.811, G40.812, G40.813, G40.814, G40.821, G40.822, G40.823, G40.824, G40.89, G40.A, G40.3, G40.30, G40.31, G40.2, G40.20, G40.21, G40.10, G40.101, G40.109, G40.11, G40.111, G40.119, G40.1, G40.0, G40.00, G40.001, G40.009, G40.011, G40.019 |
| Sfn              | Polyneuropathy                  | G62.9                                                               |
| Sma              | Spinal muscular atrophy         | G12.9, G12.0, G12.1, G12.21, G12.8                                    |
| Vst              | Venous sinus thrombosis         | G08, I67.6, E86.0, O22.50, O22.51, O22.52, O22.53, G03.9, D68.59, H70.90, Z86.718, Q24.9, H70.93 |
| Parkinsons       | Parkinsons                      | G20                                                                 |
| Gastrointestinal | Colitis                         | K50, K50.0, K50.1, K50.8, K50.9, K51, K51.0, K51.1, K51.2, K51.8, K51.9, K52, K52.1, K52.2, K52.8, K52.9 |
| Hepatitis        | Hepatitis                       | B15, B15.0, B15.9, B16, B16.0, B16.1, B16.2, B16.9, B17, B17.0, B17.1, B17.2, B17.8, B18, B18.0, B18.1, B18.2, B18.8, B18.9, B19, B19.0, B19.9 |
| Liver            | Liver disease                   | K70, K70.1, K70.2, K70.3, K70.4, K70.9, K71, K72, K72.0, K72.1, K72.9, K73, K73.0, K73.1, K73.2, K73.8, K73.9, K74, K74.1, K74.0, K74.2, K74.3, K74.4, K74.5, K74.6, K75, K76, K77 |
| Hematological    | Hem-ex                          | C81.90, C85.90, C85.92, C85.10, C85.93, C85.89, C85.80, C85.99, C88.4, C82.99, C82.80, C86.6, C83.19, C83.59, C91.60, C91.00, C91.01, C91.10, C92.00, C92.10, C92.01, C92.20, C90.00, C90.02, C90.30, Z94.81, D47.1, D46.9, D46.20, D63.0, D94.6 |
| Psychiatric      | Anxiety                          | F41.0, F41.1, F41.3, F41.8, F41, F40.0, F40, F40.1, F41.9 |
| Abbreviation | Description                              | ICD-10 Codes |  |
|--------------|------------------------------------------|--------------|---|
| Md           | Depression                               | F33, F33.0, F33.1, F33.2, F33.3, F33.4, F33.8, F33.9, F32, F32.0, F32.1, F32.2, F32.3, F32.4, F32.5, F32.8, F32.9 |  |
| Ocd          | Obsessive compulsive disorder             | F42, F42.2, F42.3, F42.4, F42.8, F42.9 |  |
| Miscellaneous| Ar                                       | J30.1, J30.9 |  |
| CTD          | Connective tissue disease                 | M30, M30.0, M30.1, M30.2, M30.3, M30.8, M31, M31.0, M31.1, M31.2, M31.3, M31.4, M31.5, M31.6, M31.8, M31.9, M32, M32.0, M32.1, M32.2, M32.3, M32.4, M32.5, M32.9, M33, M33.0, M33.1, M33.2, M33.3, M33.4, M33.5, M33.6, M33.7, M33.8, M33.9, M34, M34.0, M34.1, M34.2, M34.3, M34.4, M34.5, M34.6, M34.7, M34.8, M34.9, M35, M35.0, M35.1, M35.2, M35.3, M35.4, M35.5, M35.6, M35.7, M35.8, M35.9, M36, M36.0, M36.1, M36.2, M36.3, M36.4, M36.8 |  |
| Gerd         | Gastroesophageal reflux disease           | K21.9, Z87.81, K21.0 |  |
| Hypothyroidism| Hypothyroidism                            | E03.9, E03.8, E03.5, E03.4, E03.3, E03.2, E03.1, E03.0 |  |
| M-acid       | Acidosis                                  | E87.2, E87.4, E87.3 |  |
| Myositis     | Myositis                                  | M60.9, M60.10, M60.20, M60.009, M60.89, M61.00, M61.10, M61.50, M62.50, M62.59, M33.90, M33.20, M33.10, M33.00, M72.6, H05.129 |  |
| Oa           | Osteoarthritis                            | M15, M16, M17, M18, M19, M19.0, M19.1, M19.2, M19.9, M15.1, M15.0, M15.2, M15.3, M15.4, M15.9, M15.8 |  |
| Osa          | Obstructive sleep apnea                   | G47.33 |  |
| PU           | Peptic ulcer disease                      | K27.0, K27.9 |  |
| Disease | Group | ICD Codes |
|---------|-------|-----------|
| Pancreatitis | Pancreatitis | K85.0, K85.00, K85.1, K85.10, K85.2, K85.20, K85.3, K85.30, K85.8, K85.80, K86.0, K86.1, K85, K85.01, K85.02, K85.11, K85.12, K85.21, K85.22, K85.31, K85.32, K85.81, K85.82, K85.9, K85.90, K85.91, K85.92 |
| Ra | Rheumatoid arthritis | M06.9 |
| Rhabdo | Rhabdomyolysis | M62.82 |
| Sarcoidosis | Sarcoidosis | D86.9, D86, D86.0, D86.1, D86.2, D86.3, D86.8, D86.9 |

* Given a particular disease, it is _hx=1 if ICD ever mentioned before the event. If it’s only mentioned after the event and never before, the category without _hx =1 and the _hx one is 0. If it’s never mentioned both are 0.

### Table S4. Key phrases and groupings used to create predictors from CXR reports.

| ID | Group | Key phrases |
|----|-------|-------------|
| 1  | Multifocal | diffuse opacities  
bilateral lung opacities  
diffuse ground glass  
multifocal viral pneumonia  
multifocal pneumonia  
multifocal patchy airspace opacities  
(multifocal)...(opacit)*  
viral pneumonia  
(compatible with|may represent|suggesting|consistent within keeping with) … (viral pneumonia) *  
patchy opacity  
(patchy opacities|patchy opacities)  
new patchy airspace opacities  
patchy pneumonia  
patchy consolidation  
(consolidative|patchy)...(opacities|opacity)  
ground glass  
ground glass opacity |
|   |   |   |
|---|---|---|
|   | ground glass opacities | (groundglass)...(opacities|opacity)* ggo |
| 2 | Typical pattern for COVID-19 | typical pattern for covid consistent with covid pneumonia covid 19 pneumonia could be due to covid (seen in) … (covid) ** (concerning for) … (covid) * (compatible with|may represent|suggesting|consistent with|in (keeping with) ...(covid) * consistent with pneumonia likely representing pneumonia likely pneumonia concerning for infection (infection) … (not excluded)* can’t exclude consolidation (compatible with|may represent|suggesting|consistent with|in keeping with) … (pneumonia) * (compatible with|may represent|suggesting|consistent with|in keeping with) … (bronchopneumonia) * (compatible with|may represent|suggesting|consistent with|in keeping with) … (ards) * |
| 3 | Consolidation | focal infiltrate infiltrate consolidation (consolidation) … (not excluded)* lobe consolidation confluent airspace opacities confluent opacities consolidative opacities |
| 4 | Peripheral or interstitial opacity | peripheral opacities peripheral opacity faint interstitial opacities reticular opacities |
| Predictor                              | Range    | Unit   |
|---------------------------------------|----------|--------|
| Age                                   | 18 - 110 | year   |
| Systolic blood pressure               | 50 - 225 | mmHg   |
| Diastolic blood pressure              | 25 - 150 | mmHg   |
| Body temperature                      | 94 - 105 | °F     |
| Heart rate                            | 33 - 195 | Per minute |
| Respiratory rate                      | 8 - 55   | Per minute |
| BMI                                   | 9 - 80   | kg/m²  |
| SpO₂                                  | 50 - 100 | %      |
Table S6. Reasons for being included in either development or prospective cohorts

| Reason                                                                 | n    | %  |
|-----------------------------------------------------------------------|------|----|
| Possible COVID Related                                                | 4163 | 35.9|
| Pain|Medication Refill|Other                         | 1638 | 14.1|
| Gastrointestinal|Urinary - Unlikely COVID Related                                   | 1043 | 9  |
| Neurological|ENT|Ophthalmological                                                   | 841  | 7.3 |
| Surgical|Trauma|Vascular|Skin, Soft tissue, Bone, Blood Infection                      | 777  | 6.7 |
| Cardiac|Pulm - Unlikely COVID Related                                       | 546  | 4.7 |
| Psychiatry|Substance Use|Overdose                                                                 | 537  | 4.6 |
| Endocrine|Rheumatological|Dermatological                                                              | 93   | 0.8 |
| Abnormal Lab|Imaging                                                                 | 51   | 0.4 |
| Gyn|Obstetrics                                                          | 43   | 0.4 |
| Missing                                                              | 1854 | 16  |

Table S7. Univariate association of each predictor and the outcome.

| Predictor                  | log_{10}(p-value) |
|----------------------------|-------------------|
| SpO2                       | -272.5            |
| Age                        | -271.5            |
| Diastolic blood pressure   | -238.1            |
| Respiratory rate           | -155.6            |
| CCI                        | -133.6            |
| Chf_hx                     | -74.2             |
| Systolic blood pressure    | -59.2             |
| Body temperature           | -54.7             |
| Pneumonia_hx               | -50.6             |
| Cad_hx                     | -49.5             |
| Aki_hx                     | -47.0             |
| Htn_hx                     | -47.0             |
| Condition                        | Value  |
|---------------------------------|--------|
| Ckd-end_hx                      | -46.4  |
| Ckd-iv_hx                       | -46.4  |
| High BMI (>35kg/m²)             | -44.2  |
| Dm_hx                           | -28.6  |
| Ais_hx                          | -25.5  |
| TobaccoUserDSC                  | -17.3  |
| Mg_hx                           | -16.4  |
| Copd_hx                         | -15.9  |
| Renal-cx_hx                     | -15.2  |
| Low BMI (<18.5kg/m²)            | -15.0  |
| Ich_hx                          | -14.5  |
| Arrythmia_hx                    | -13.9  |
| sex                             | -13.1  |
| M-acid_hx                       | -11.9  |
| Hem-cx_hx                       | -11.3  |
| Arrest_hx                       | -9.6   |
| Als_hx                          | -9.5   |
| Pancreatitis_hx                 | -9.4   |
| Sdh_hx                          | -9.3   |
| HR                              | -9.1   |
| CM_hx                           | -8.4   |
| Neuropathy_hx                   | -7.5   |
| Sma_hx                          | -6.3   |
| Condition             | Value |
|-----------------------|-------|
| Sah_hx                | -6.0  |
| Anxiety_hx            | -5.7  |
| Seizure_hx            | -5.2  |
| Ards_hx               | -4.8  |
| Ild_hx                | -4.7  |
| Pneumothorax_hx       | -4.6  |
| Vst_hx                | -4.4  |
| Parkinsons_hx         | -4.2  |
| Bronchitis_hx         | -3.9  |
| Hypothyroidism_hx     | -3.3  |
| Ow_hx                 | -3.2  |
| Sfn_hx                | -3.0  |
| Pericarditis_hx       | -3.0  |
| Ar_hx                 | -2.8  |
| Brain-cx_hx           | -2.6  |
| CTD_hx                | -2.6  |
| Ce_hx                 | -2.3  |
| Movement_hx           | -2.1  |
| Colitis_hx            | -2.1  |
| Cf_hx                 | -2.1  |
| Hydrocephalus_hx      | -2.0  |
| Ra_hx                 | -1.9  |
| Osa_hx                | -1.6  |
| Condition          | Score |
|--------------------|-------|
| Md_hx              | -1.5  |
| Myositis_hx        | -1.2  |
| Sarcoidosis_hx     | -1.1  |
| Pn_hx              | -1.1  |
| Anosmia_hx         | -0.9  |
| CIM_hx             | -0.8  |
| Ocd_hx             | -0.8  |
| Inf-men-enc_hx     | -0.7  |
| Oa_hx              | -0.7  |
| Gbs_hx             | -0.6  |
| Obesity_hx         | -0.6  |
| Dysgeusia_hx       | -0.5  |
| Asthma_hx          | -0.5  |
| PU_hx              | -0.5  |
| Hiv_hx             | -0.5  |
| Rhabdo_hx          | -0.5  |
| Cmt_hx             | -0.4  |
| CIN_hx             | -0.3  |
| Gerd_hx            | -0.3  |
| Ms_hx              | -0.3  |
| Hepatitis_hx       | -0.3  |
| Coma_hx            | -0.2  |
| Tb_hx              | -0.2  |
| Condition               | Value |
|-------------------------|-------|
| Myocarditis_hx          | -0.1  |
| Neuromuscular_hx        | 0.0   |
| Ih_hx                   | 0.0   |
Figure S1. Data flowchart to generate the predictors and outcomes for the development and prospective cohorts.

Figure S2. Distribution of adverse events at different decades and sexes. (A) Development cohort; (B) Prospective cohort.
**Figure S3.** Model training and validation schema. Concurrent validation in the model development cohort is based on nested cross-validation. Prospective validation is done using the final model trained on the development cohort.

**Figure S4.** Relationship in the CoVA score between pre- and post-test probability (critical illness or death) following a chest X-ray (CXR) (left) or COVID-19 testing (right). The diagonal line shows the pre-test probability. The blue curve shows the post-test probability following a positive test result (e.g. both CXR findings in the CoVA model are present, or positive COVID-19 test). The red curve shows the post-test probability following a negative result. Black dots show the values for which a positive or negative test result causes the large difference between the pre- and post-test probability, i.e. the pre-test probabilities at which testing is maximally informative. For CXR, the positive results cause the largest increase (4%) when the pre-test probability is 30%, and the largest decrease (4%) when the pre-test probability is 34%. For COVID-19 testing, the maximal increase or decrease (8%) occur at pre-test probabilities of 28% or 36%, for positive vs negative test results, respectively.
Figure S5. Heatmap of p-values representing the statistical significance of pairwise correlations between final model variables and variables not selected by LASSO. Rows represent final model variables, and columns represent variables that are univariately associated with outcomes, but were not selected by LASSO. For pairs of continuous variables we computed the p-value of the Spearman’s rank correlation, for pairs of binary variables the Phi coefficient, and for continuous-binary pairs the biserial correlation. p-values are binned into p < 0.05, 0.05 < p < 0.01, 0.01 < p < 0.02, and p > 0.02. Shade indicates the magnitude of the p-value bin, where the darkest shade of blue indicates p < 0.05, and progressively lighter shades indicate bins of progressively higher p-values.

Abbreviations: CXR = chest X-ray; AIS = Acute Ischemic Stroke; AKI = Acute Kidney Injury; ALS = Amyotrophic Lateral Sclerosis; AR = Allergic Rhinitis; ARDS = Acute Respiratory Distress Syndrome; Arrest = Cardiac Arrest; Brain Cx = Brain Malignancy; CAD = Coronary Artery Disease; CE = Cerebral Edema; CCI = Charlson Comorbidity Index; CF = Cystic Fibrosis; CHF = Congestive Heart Failure; CKD-End = End Stage Renal Disease; CKD-IV = Stage Four Chronic Kidney Disease; CM = Cardiomyopathy; COPD = Chronic Obstructive Pulmonary Disease; COVID+ = COVID+ test up to point of visit; CTD = Connective Tissue Disorder; CXR Typical = CXR: Typical for COVID; Diastolic = Diastolic blood pressure; DM = Diabetes Mellitus; Hem Cx = Hematologic malignancy; HTN = Hypertension; ILD = Interstitial Lung Disease; M. Gravis = Myasthenia Gravis; MD = Major Depressive Disorder; OSA = Obstructive Sleep Apnea; OW = Overweight; RA = Rheumatoid Arthritis; Renal Cx = Renal cancer; Resp. Rate = Respiratory Rate; SAH = Subarachnoid hemorrhage; SDH = Subdural
Hematoma; Seizure = Seizure disorder; SFN = Small Fiber Neuropathy; SMA = Spinal Muscular Atrophy; Systolic = Systolic blood pressure. Tobacco = Tobacco User; VST = Venous Sinus Thrombosis.

All diagnoses are pre-existing conditions based on past medical history, and are coded as present (e.g. Pneumothorax = 1) if recorded in the electronic medical record at any time before the date of presentation for COVID-19 screening.