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Case report

Developing a COVID-19 WHO Clinical Progression Scale inpatient database from electronic health record data

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Abstract

Objective: There is a need for a systematic method to implement the World Health Organization's Clinical Progression Scale (WHO-CPS), an ordinal clinical severity score for coronavirus disease 2019 patients, to electronic health record (EHR) data. We discuss our process of developing guiding principles mapping EHR data to WHO-CPS scores across multiple institutions.

Materials and Methods: Using WHO-CPS as a guideline, we developed the technical blueprint to map EHR data to ordinal clinical severity scores. We applied our approach to data from 2 medical centers.

Results: Our method was able to classify clinical severity for 100% of patient days for 2756 patient encounters across 2 institutions.

Discussion: Implementing new clinical scales can be challenging; strong understanding of health system data architecture was integral to meet the clinical intentions of the WHO-CPS.

Conclusion: We describe a detailed blueprint for how to apply the WHO-CPS scale to patient data from the EHR.

Key words: public health informatics, medical informatics, electronic health records, World Health Organization, COVID-19

BACKGROUND AND SIGNIFICANCE

The 2019 novel coronavirus disease (COVID-19) pandemic prompted health organizations to develop best practices to facilitate rapid, but scientifically rigorous clinical research.^{1,2} In August 2020,

the World Health Organization (WHO) Research and Development Blueprint initiative's Clinical Characterisation and Management Working Group, with several other organizations, introduced the WHO Clinical Progression Scale (WHO-CPS) to study COVID-19's

burden on a health system.³ For *hospitalized* patients with COVID-19, the WHO-CPS scores progress from 4 to 10 with increasing severity. Scores of 4, 7, and 10 denote no oxygen support, invasive (IV) ventilation required, and death, respectively. By implementing this scale, health systems may transparently and reproducibly track a patient's clinical trajectory based on respiratory disease progression and end-organ dysfunction.

Researchers at 2 tertiary-care academic centers, University of California, San Francisco (UCSF) and University of Texas Southwestern Medical Center (UTSW), aimed to use the WHO-CPS to study the clinical progression of COVID-19 and associated hospital burden. Examples of study questions included: *How do social determinants of health affect in-hospital COVID-19 outcomes?* and *How can we create prediction models for allocating hospital resources?* While both institutions had similarly structured electronic health record (EHR) data, there were areas of ambiguity in how to apply WHO-CPS scores to real-life data. It was essential to standardize data collection definitions and WHO-CPS scoring rules for performing analyses that generalize across multiple health systems.⁴ While blueprints exist to analyze COVID-19 data with Systematized Nomenclature of Medicine–Clinical Terms and Logical Observation Identifiers Names and Codes,⁵ no guidelines exist to assign WHO-CPS based on EHR data.

We present our blueprint of assigning WHO-CPS scores to real data. Our blueprint components include:

1. EHR elements required to implement WHO-CPS scoring,
2. Categorization of respiratory support devices, and
3. Pseudocode to implement the maximum WHO-CPS score per hospital day.

Since data collection may differ across EHRs, it is important to share a transparent process for developing and validating cross-institutional measures. We hope our WHO-CPS blueprint can serve as a useful baseline for others to study their health system's COVID-19 burden.

MATERIALS AND METHODS

Data retrieval alignment

In January 2021, UCSF and UTSW researchers began the process of implementing the WHO-CPS as a measure to standardize and compare clinical progression and hospital burden across both sites. Each institution's Independent Review Boards approved the research and data-use agreements were established.

Microsoft SQL Server was used to query data from similarly structured tables within each institution's Epic Clarity data warehouse. [Figure 1](#) shows the generalized star schema of queried data elements, each with appropriate date and timestamps, linked by a deidentified and unique SQL-generated patient-encounter ID. This data query created our COVID-19 patient encounter report (C19-Report). See [Supplementary Material](#) for data normalization details.

Database development

Data and column definitions

Each row of C19-Daily, a clinical and resource utilization database built using Python (version 3.8.1), was designed to summarize each hospital day (defined after midnight) per patient encounter. [Table 1](#) defines the data columns of the C19-Daily. The WHO-CPS scoring logic utilizes the data column values to assign a per day (row) score.

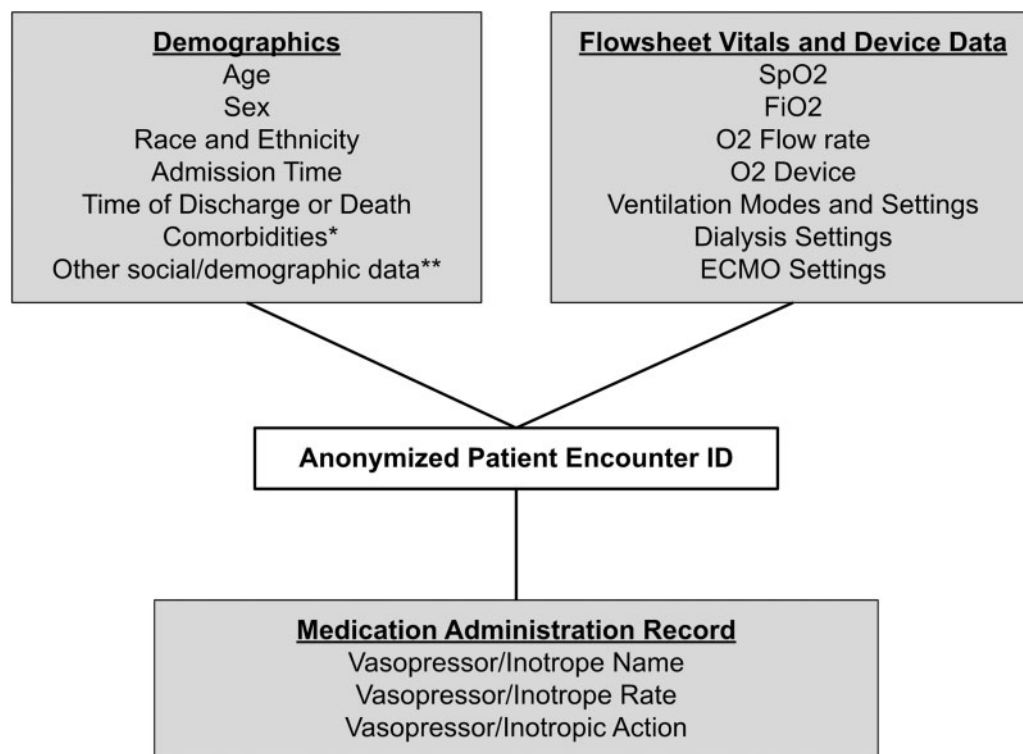


Figure 1. Star schema for COVID-19 patient encounter report. *Comorbidity data collected were the ICD-10 codes linked to a patient's medical history at the time of admission. **Other social/demographic data includes zip code, insurance type, smoking status, marital status, and language.

Table 1. COVID-19 Daily database structure for WHO-CPS assignment

C-19 Daily Database Structure for WHO-CPS Assignment					
Encounter ID	LOS	Day	Date	Data Columns**...	WHO-CPS
1A12138186	5	0	2020-04-01	4
1A12138186	5	1	2020-04-02	5
1A12138186	5	2	2020-04-03	7

↓ **Transposed Data Columns**

Data Columns:	Value Type	Patient Daily Event Description
O2 Use	Binary (1/0)	True if O2 flow rate > 0 or FiO2 > 21%.
LowFlow	Binary	True if 0 < O2 flow ≤ 12 L/min
HighFlow	Binary	True if O2 flow > 12 L/min
NC_12	Binary	True if NC's or HFNC's O2 Flow rate > 12 L/min NC or HFNC with O2 flow rate > 12 L/min would meet criteria for WHO-CPS Score 6. NC was included to account for technician errors in mis-documentation.
HFNC_12		
SIMPLE	Binary	True if received support from a simple device
SIMPLE_n	Integer	Number of instances of a simple device recorded that day
NC_n	Integer	Number of instances of a NC recorded that day
CPAP	Binary	True if received support from a CPAP device
NIV	Binary	True if received support from a NIV device
NIV_n	Integer	The number of instances of a NIV device recorded that day
HFNC_n	Integer	The number of instances of a HFNC device recorded that day
IV	Binary	True if received support from an IV device Based on instances of recorded IV device name or IV device settings
SF200	Binary	True if SpO2/FiO2 < 200 during same timestamp
HD	Binary	True if received HD Based on instances of recorded HD device or settings
CRRT	Binary	True if received CRRT Based on instances of recorded CRRT device or settings
Vasopressor	Binary	True if vasopressor/inotrope infusion rate > 0
ECMO	Binary	True if received ECMO Based on record of ECMO device or settings
Death	Binary	True if time of death recorded

Note: Daily WHO-CPS scores are assigned based on derived data columns, based on definitions applied to EHR data.

**Transposed data columns shown.

LOS: length of stay; WHO-CPS: World Health Organization's Clinical Progression Scale.

O₂: oxygen; FiO₂: fraction of inspired oxygen; L/min: liters/minute, NC: nasal cannula; HFNC: high-flow nasal cannula; WHO-CPS: World Health Organization Clinical Progression Scale; CPAP: continuous positive airway pressure; NIV: noninvasive ventilation; IV: invasive ventilation; SpO₂: oxygen saturation; HD: hemodialysis; CRRT: continuous renal replacement therapy; ECMO: extracorporeal membrane oxygenation.

Logic criteria

Defining the C19-Daily's specific column categories was nontrivial, given the need to map categorized EHR data to clinically meaningful classifications for WHO-CPS scoring. *Given the variety of oxygen support devices, for example, which ones should be categorized as simple versus noninvasive/high-flow (NIV)? Should we separate intermittent hemodialysis (HD) for chronic end-stage renal disease from continuous renal replacement therapy (CRRT) for acute kidney injury?* These types of decisions impact how clinical severity scores are assigned. Consensus definition and categorization decisions were developed during weekly meetings and through expert consultations with specialty-trained physicians, clinical informaticians, and public health experts. Based on the complexities of how EHR data were recorded and the nuances of worsening end-organ dysfunction, we relied on 3 guiding principles to assist with clinical interpretation:

- *Principle 1:* A higher WHO-CPS score should coincide with evidence of worsening clinical status (either worsening of a single organ or presence of multiple organ damage).
- *Principle 2:* Multiple consistent observations (eg, oxygen (O₂) flow >12 L/min and high-flow nasal cannula [HFNC]) should be used to define a score transition to mitigate user entry errors.
- *Principle 3:* Chronic device usage (eg, dialysis in pre-existing renal disease) should not affect clinical severity score.

Consensus guidelines for scoring clinical severity based on EHR data

Categorization of respiratory support

WHO-CPS scores 4 through 7 were determined by the level of respiratory support a patient required: "none," "simple," "NIV," or "IV." For many oxygen devices present in our data set, it was not immediately obvious which respiratory support category was the

most correct based on prior literature. Based on group consensus, [Table 2](#) summarizes the categories of respiratory devices. For example, differentiating our device classifications between simple and NIV were based on both the patterns of how respiratory care was escalated at each institution and the additional resources required (eg, nursing staff, monitoring equipment, or respiratory therapist).

Calculation of SpO₂/FiO₂

To distinguish between WHO-CPS scores 7, 8, and 9, it was necessary to calculate whether SpO₂/FiO₂ ratios were greater than or equal to 200. Given continuous monitoring for ventilated patients in our hospitals, there existed a plethora of concurrent FiO₂ and SpO₂ measurements pulled automatically into the EHR.

Respiratory Severity Index (SF200)

$$= 0 \text{ if } \left\{ 100 \times \frac{\text{SpO}_2 \text{ at } T}{\text{FiO}_2 \text{ at } T} \right\} \geq 200, \text{ else } = 1, \text{ where } T = \text{Time}$$

Categorization of vasopressors

Regardless of respiratory support, the infusion of pressors, a sign of end-organ dysfunction, immediately elevates a patient to a WHO-CPS score of 8. This decision point also aligned with our resource utilization and clinical workflow, as patients receiving continuous pressors require intensive care. Similarly, we expanded the interpretation of vasopressor to include inotropes. Patients were classified as being on vasopressors each day if they received an infusion rate of the listed vasopressors/inotropes shown in [Table 2](#). If no flow rates were recorded for 3 continuous hours, they were assumed to be discontinued (since documentation is required hourly). Vasopressor push doses were excluded, as these may be administered on nonintensive care areas as a temporizing measure. Last resort pressors,^{6,7} like methylene blue or angiotensin II, were also excluded because they are sometimes used for conditions other than shock.

Table 2. Respiratory support categorization and vasopressors/inotropes utilized for WHO-CPS score classification

Respiratory support categorization			
None	Simple	Noninvasive ventilation (NIV)	Invasive (IV)
None/room air	Aerosol mask	Bag valve mask	Ventilator
Cool mist	Nasal cannula ^b	Bilevel positive airway pressure (BiPAP)	Mechanical ventilator
Heated humidified (air)	Nasal cannula with reservoir	High-flow nasal cannula ^b	
Other ^a	(ie, oxymizer)	Nonrebreather mask	
	Blow-by	T-Piece/Tracheal-ring	
	Nasal cannula	Transtracheal catheter	
	Simple mask	Venturi mask	
CPAP	Open oxygen mask	High-flow mask	
Continuous positive airway pressure (CPAP)	Partial rebreather mask	High-flow nasal cannula	
	Trach mask	Manual resuscitator	
	Tracheostomy collar	Noninvasive positive pressure ventilation/Noninvasive ventilation	
	Face tent		
Vasopressors/inotropes			
Dobutamine		Milrinone	
Dopamine		Norepinephrine	
Ephedrine		Phenylephrine	
Epinephrine		Vasopressin	

WHO-CPS: World Health Organization's Clinical Progression Scale.

^aIf no comment/free text left (data missing), categorized as None.

^bThese are flow-dependent. Flows ≤12 L/min were classified as Simple, while flows ≥12 L/min classified as NIV/HF.

Classification of end-stage renal disease and dialysis

We excluded intermittent HD while assigning the WHO-CPS. First, distinguishing end-stage renal disease with chronic intermittent HD versus new intermittent HD is nontrivial. Second, CRRT requires intensive-care resources staff, while intermittent HD is available in nonintensive care settings at our hospitals.

Missing data

At both institutions, vital signs and device data were recorded every 4 h, at minimum, and more frequently in higher acuity settings. Fortunately, our goal was to implement a daily, not hourly, WHO-CPS score. Nevertheless, we handled the relevant instances of missing data as follows:

1. No device and O₂ flow recorded is interpreted as no oxygen delivered to the patient.
2. If only a single instance of a device was recorded without recorded oxygen flow rate or device settings (eg, BIPAP) that day, then it was deemed a fluke recording. This instance was interpreted as no oxygen delivered to the patient.
3. When multiple instances of invasive ventilator settings were recorded in the absence of a recorded device, a minimum WHO-CPS score of 7 was assigned (eg, occurred during prolonged intubation).

Daily WHO-CPS assignment

Given the amount of disease progression a patient can experience even within a single day, we decided to assign the maximum WHO-CPS score reached per day. We felt this approach represented the best proxy for hospital-resource use. Figure 2 shows the WHO-CPS staging algorithm pseudocode, which is applied to the C19-Daily.

RESULTS

From March 1, 2020 to February 9, 2021, UCSF had 918 patient encounters spanning 13 386 patient days, while UTSW had 1838

patient encounters spanning 19 049 patient days, respectively. We were able to assign the WHO-CPS to 100% of inpatient days. Figure 3 showcases the WHO-CPS score trends at UCSF and UTSW medical centers.

DISCUSSION

We have developed a blueprint for reproducible, transparent assignment of clinical severity for each patient-day of a hospitalized COVID patient. While EHR variation may certainly be a limitation, we believe others can utilize our blueprint to implement a comparable assignment of WHO-CPS scores if similarly structured data are recorded. There are some challenges to our blueprint's generalizability. We were fortunate to have reliable, automatically captured data in our EHRs with the same timestamps to calculate SpO₂/FiO₂. However, at other institutions a delay may exist between timestamps. Additionally, not all EHRs will lead to an as detailed C-19 Report, unrecorded or missing data may require institutions to modify the C19-Daily column definitions.

Since COVID-19 primarily affects the respiratory system,⁸ much consideration went into classifying respiratory devices, especially since no consensus exists. For example, a transtracheal catheter (TTC) can be classified as IV (enters a tracheostomy site), NIV, or simple (flow rates are generally between 6 and 11 L/min). Based on clinical experience and following *Guiding Principle 1*⁷ we classified TTC as NIV because it was more invasive than a simple face mask over the tracheostomy site but not as intensive as mechanical ventilation through tracheostomy. Similarly, a nonrebreather (NRB) was classified under NIV; while technically a low-flow device, in practice, it represents an escalation of respiratory care from a simple face mask. Our comprehensive list of respiratory support devices and their respective categorizations may be applicable to research beyond COVID-19 care.

Prior work has underscored the importance of using EHR data for COVID-19 research, especially highlighting the need for data interoperability.⁹ However, implementing clinical scales developed by leading organizations like the WHO in a reproducible manner can

Pseudocode: WHO-CPS Stage per Hospital Day

```

if Death==1:
    return 10
else if ECMO==1 OR (IV==1 AND SF200==1 AND (Vasopressor==1 OR CRRT==1)):
    return 9
else if (IV==1 AND SF200==1) OR Vasopressor==1 OR CRRT==1:
    return 8
else if IV==1 AND SF200==0:
    return 7
else if ((NIV == 1) AND (NIV_n - HFNC_n >0 AND HFNC_n ==1)) OR (HFNC_12 == 1) OR ((NC_n > 0) AND (NC_12 == 1))
    return 6 % scores WHO-CPS Score 6 for NC or HFNC with O2 Flows > 12
else if (SIMPLE==1 AND (LowFlow==1 OR HighFlow==1 OR SIMPLE_n>1)) OR (HFNC_n >0 AND HFNC_12 ==0):
    return 5 %scores WHO-CPS score 5 for NC or HFNC with O2 flows <=12
else if (SUM('NIV', IV, 'SIMPLE') == 0) AND (LowFlow==1 OR HighFlow==1): % captures O2 flow when oxygen devices
not documented
    return 5
else:
    return 4

```

Figure 2. Pseudocode for assigning a maximum WHO-CPS score per hospital day for each patient encounter, based on C19-Daily data columns. WHO-CPS: World Health Organization's Clinical Progression Scale.

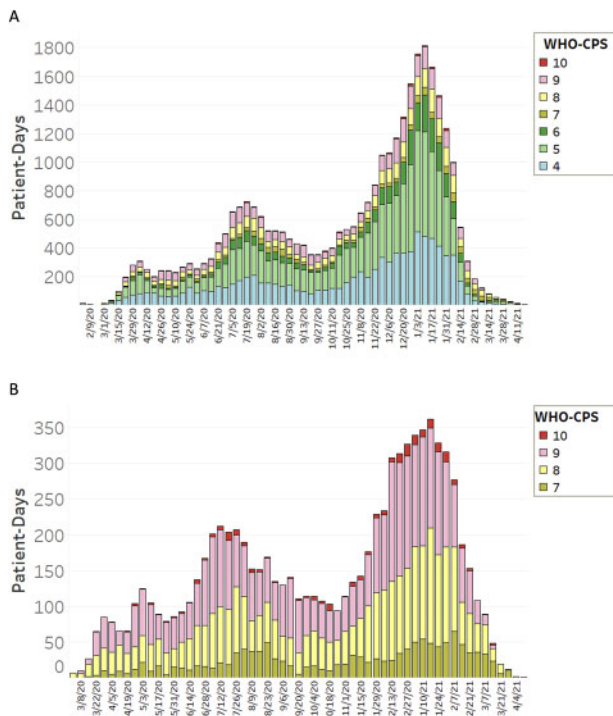


Figure 3. Patient-days per week at each WHO-CPS scale on aggregate UTSW and UCSF. Total number of patient days at each WHO-CPS stage per week across aggregate UCSF and UTSW are shown. From February 3, 2020 to April 22, 2021, there were 32 435 patient days spanning 2756 patient hospital admissions. (a) Shows WHO-CPS scores 4–10 while (b) shows only WHO-CPS scores 7–10, capturing severe disease (ICU level care) and death. UCSF: University of California, San Francisco; UTSW: University of Texas Southwestern Medical Center; WHO-CPS: World Health Organization’s Clinical Progression Scale.

be challenging, especially across multiple sites. Our WHO-CPS blueprint is designed to maximize generalizability of results from multi-institutional studies and strengthen the statistical significance of differences observed between sites.¹⁰ Our algorithm intentionally assigns a score for each day based on our best understanding of respiratory status for a patient. This does not mean we do not have missing data in EHR documentation, but rather we have a method of adapting for it. Despite possible gaps in clinical data, we can reproducibly and transparently assign a WHO-CPS score each day. Clinical informaticians were essential in faithfully translating the local data architectures and definitions to match the clinical intentions of the original health scale, thus promoting robust data interoperability across different sites. A clinical informatician can not only understand, articulate, and champion the clinical significance of such scores but also ensure robust semantic interoperability of data to faithfully implement such scores locally or across institutions.¹¹

CONCLUSION

Implementing clinical risk scores is challenging, as a series of important yet often undocumented decisions must be made due to the ambiguity of individual EHR data elements. We developed a detailed blueprint outlining how the WHO-CPS can be applied to EHR data. The development of national or international clinical scoring systems may benefit from the input of a clinical informatician to marry medical interpretation and technical data definitions. This approach would help assure data quality, consistency and mitigate varying

institution-specific interpretations. While WHO-CPS scoring has areas of nuanced interpretation, we highlight how institutions can create a C19-Daily database to implement the WHO-CPS scoring in a reproducible, standardized, and transparent manner. In the future, we hope to utilize the WHO-CPS to study how patient severity changes over time and eventually develop severity prediction models. We hope our methods may be helpful to others who wish to implement WHO-CPS scoring quickly and efficiently.

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AUTHOR CONTRIBUTIONS

PR contributed to the conception, design, data analysis and interpretation, drafted, and critically revised the article. JG contributed to the conception, design, data analysis and interpretation, and critically revised the article. SS contributed to the conception, design, data acquisition, data analysis and interpretation, and critically revised the article. SMD contributed to the conception, design, data interpretation, and critically revised the article. SB contributed to the conception, design, data interpretation, and revised the article. RM contributed to the conception, design, data interpretation, and critically revised the article. XL contributed to the conception, design, data acquisition and interpretation, and critically revised the article.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Journal of the American Medical Informatics Association* online.

CONFLICT OF INTERESTS STATEMENT

None declared.

DATA AVAILABILITY

Data cannot be shared publicly to protect the privacy of patients. The derived data may be shared on reasonable request to the corresponding author.

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