

## Supplementary Online Content

Byrd TF, Southwell B, Ravishankar A, et al. Validation of a proprietary deterioration index model and performance in hospitalized adults. *JAMA Netw Open*. 2023;6(7):e2324176.  
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**eMethods.** The Epic Deterioration Index, Rationale for Observation-Level and Encounter-Level Analyses, and Confirmatory Records Review

**eFigure 1.** Receiver Operating Characteristic and Precision Recall Curves

**eFigure 2.** Calibration Plot of Observation-Level Predictions

**eFigure 3.** Calibration Plot of Encounter-Level Predictions

**eTable 1.** Ethnicities Included in *Other Ethnicity* Category

**eTable 2.** Records Review Instrument

### eReferences

This supplemental material has been provided by the authors to give readers additional information about their work.

**eMethods.** The Epic Deterioration Index, Rationale for Observation-Level and Encounter-Level Analyses, and Confirmatory Records Review

### *The Epic Deterioration Index*

The model is an ordinal logistic regression model that categorizes patients into three risk buckets: green (low), yellow (medium), and red (high). The model developers decided to construct two linear combinations of clinical inputs that, using the proportional odds assumption, allows the feature space to be split into two decision boundaries. The target (a.k.a outcome or dependent variable) for model training was an ordinal integer: 2 if the patient dies in the next 38 hours (red risk), 1 if the patient does not die in the next 38 hours but is transferred to the ICU or has a rapid response team (RRT) or code called in the next 12 hours (yellow risk), and 0 if neither of the listed events occur (green risk). The model uses the following independent variables: age, systolic blood pressure, temperature, pulse, respiration rate, SpO<sub>2</sub>, several nursing assessments ('Glasgow Coma Score', 'abnormal neurologic assessment', 'abnormal cardiac rhythm', 'on oxygen'), hematocrit, WBC, potassium, sodium, blood pH, abnormal platelet count, and abnormal BUN.

### *Rationale for observation-level and encounter-level analyses*

Observation- and encounter-level measurements are two distinct approaches to defining the performance of an early warning system, and each highlights different model strengths and weaknesses. At the observation level, each prediction (in this case made every fifteen minutes) counts equally. Therefore, a single high or low prediction is unlikely to change the overall performance. However, a string of high predictions wherein the outcome subsequently does not occur, as might be seen in a patient who has multiple advanced chronic diseases admitted for an extended time while awaiting placement, will bring down model performance. Besides giving excess weight to patients with longer hospitalizations, observation-level measurements do not take into account "muting" or ignoring subsequent predictions after an initial high-risk prediction.

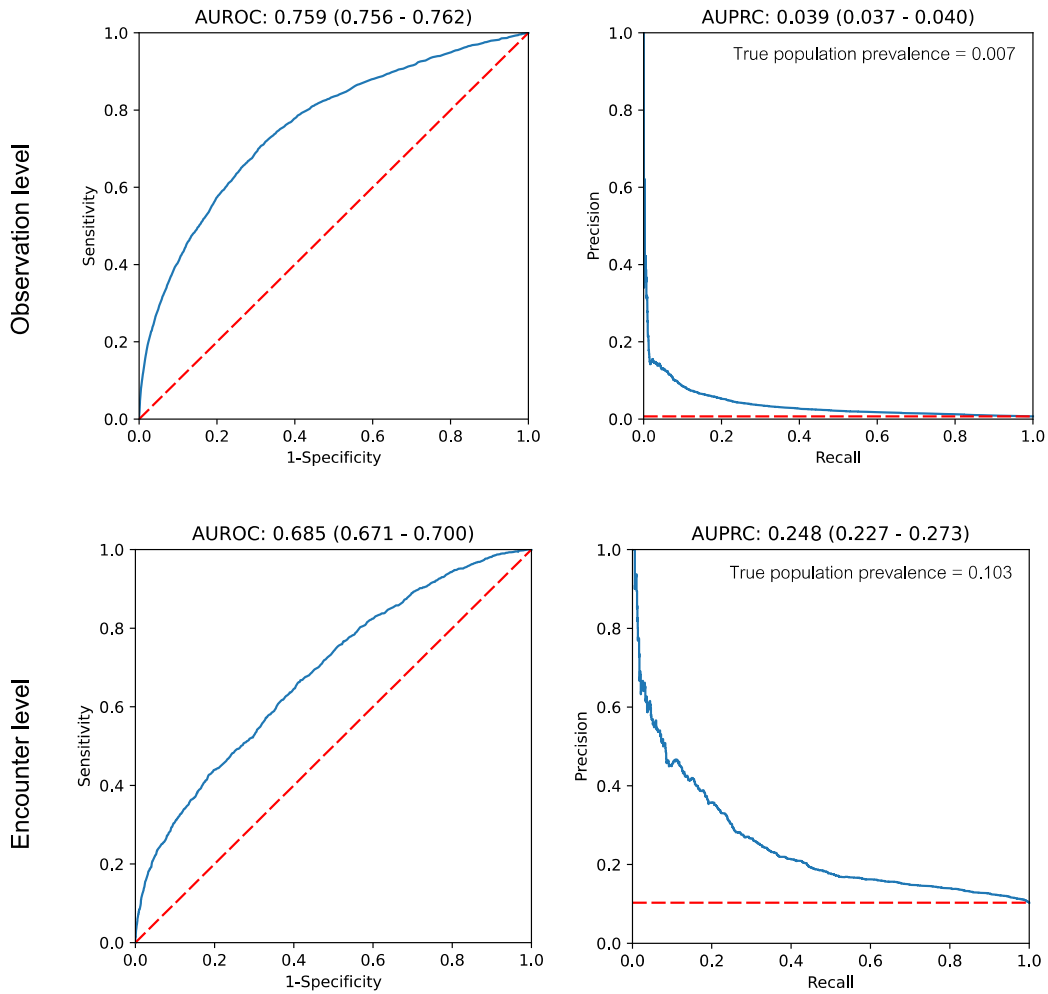
In contrast, a single erroneous encounter-level prediction will bring down performance. By including only the highest deterioration score in encounter-level predictions, this analysis approximates the model's performance as if it was linked to an alert that only fires once during an admission - if the patient crossed a pre-defined high risk threshold. In the encounter-level analysis, each patient is represented by a single prediction, making it a more appropriate measurement for studying bias in smaller subgroups. This contrasts with the observation-level analysis, where a single patient could contribute hundreds of predictions, potentially skewing the analysis.

### *Confirmatory records review*

We sampled encounters of patients in our study cohort who experienced any of the following events while hospitalized: mechanical ventilation, ICU transfer, mortality, vasopressor initiation, or comfort care initiation. Epic measures the performance of EDI retrospectively across hospitalizations by sampling predictions up to 38 hours before deterioration occurs. To match this time frame, we kept the highest EDI score made within 38 hours prior to the first event for each hospitalization. We binned these predictions into deciles so we could evenly sample the entire probability range of EDI scores. We then randomly selected five encounters from each score decile to create our final set of 50 hospitalizations for chart review.

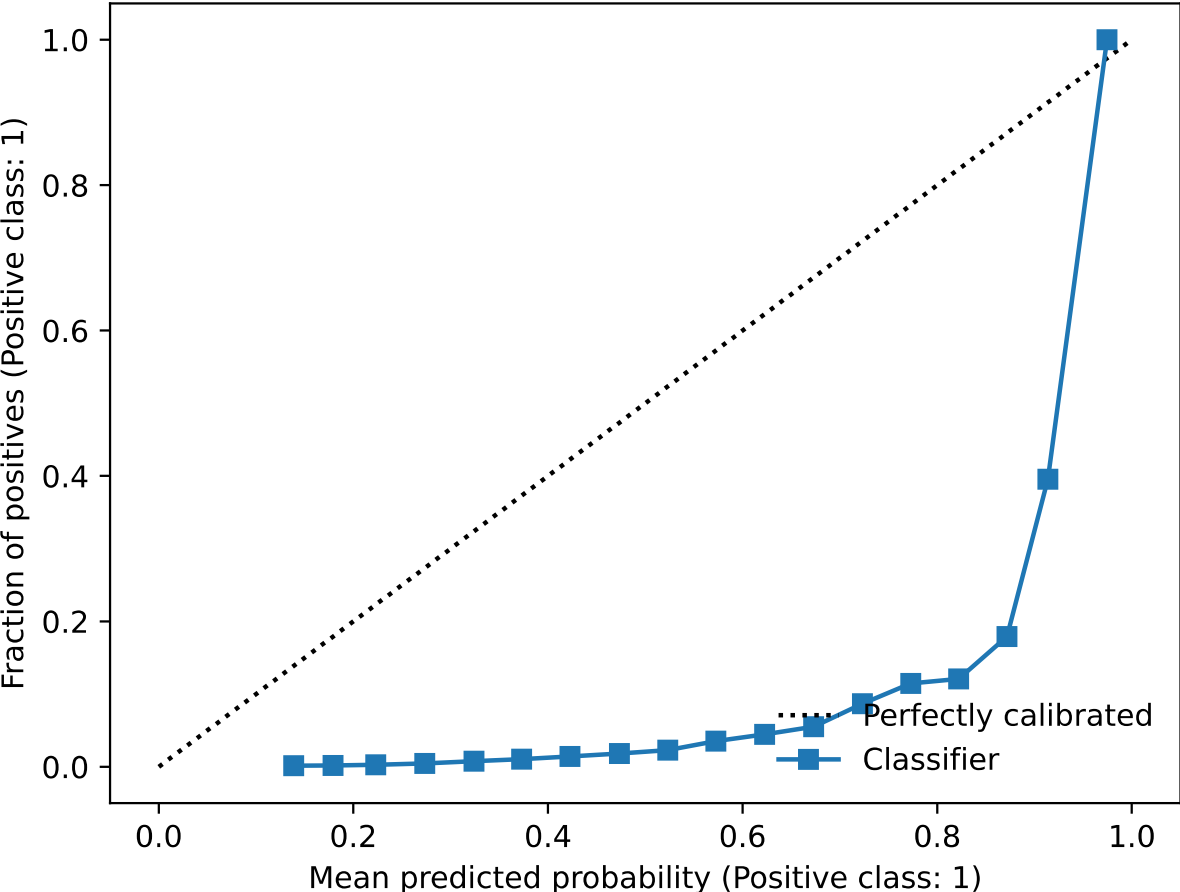
Three physicians on the research team (BS, AR, TT) independently completed chart reviews and entered data into a REDCap electronic data capture tool hosted at the University of Minnesota.<sup>1,2</sup> We designed a custom data collection form to explore the timing of, events surrounding, and preventability of deterioration episodes, adapted from van Galen et al.<sup>3</sup> The form was comprised of a mix of discrete multiple-choice, date/time, Likert-style, and free-text items, as given in eTable 2. After independently reviewing the first ten cases, the team met and resolved areas of confusion and ambiguity through discussion. BS, AR, and TT then each reviewed all remaining cases (a total of three independent reviews per case). TB and AK audited select cases where the reviewers did not reach a consensus, made final determinations as appropriate, and compiled the data.

**eFigure 1.** Receiver Operating Characteristic and Precision Recall Curves

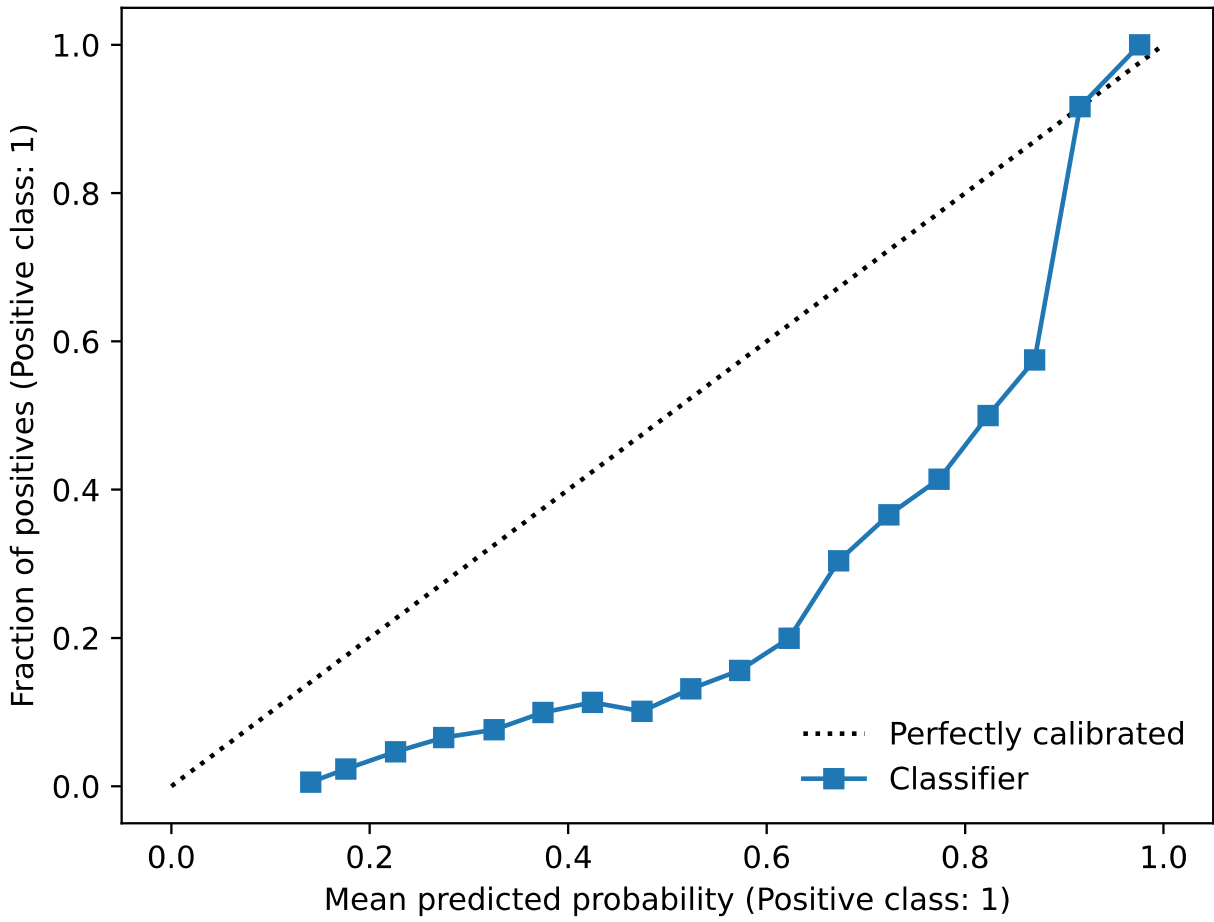


Overall DTI performance. AUROC = area under the receiver operation curve. AUPRC = area under the precision recall curve. Diagonal dashed lines: AUROC reference (AUROC of 0.5). Horizontal dashed lines: AUPRC reference (deterioration prevalence).

**eFigure 2.** Calibration Plot of Observation-Level Predictions



**eFigure 3.** Calibration Plot of Encounter-Level Predictions



**eTable 1.** Ethnicities Included in *Other Ethnicity* Category

<b>Ethnicity</b>	<b>n</b>	<b>%</b>	<b>Ethnicity</b>	<b>n</b>	<b>%</b>
AFRICAN-AMERICAN	13	0.09	Israeli	1	0.01
African	20	0.14	Japanese	10	0.07
African American	11	0.08	Karen	2	0.01
American	5,424	38.97	Kenyan	21	0.15
Arabic	15	0.11	Korean	29	0.21
Asian	21	0.15	Laotian	20	0.14
Asian/Pacific Island	2	0.01	Latino	28	0.2
Bhutanese	2	0.01	Lebanese	9	0.06
Bosnia-Herzegovian	2	0.01	Liberian	16	0.11
Burmese	1	0.01	Mexican	89	0.64
Cambodian	17	0.12	Moroccan	3	0.02
Cameroon	6	0.04	Native Hawaiian/Other Pacific Island	2	0.01
Canadian	6	0.04	Nepalese	6	0.04
Caucasian	277	1.99	Nigerian	26	0.19
Chinese	46	0.33	Not Hispanic or Latino	4,664	33.51
Colombian	3	0.02	Oromoian	7	0.05
Congolese	2	0.01	Other	977	7.02
Croatian	8	0.06	Pakistani	4	0.03
Ecuadorian	10	0.07	Russian	39	0.28
Egyptian	7	0.05	Serbian	2	0.01
El Salvadorian	10	0.07	Sierra Leone	5	0.04
Eritrean	7	0.05	Somali	199	1.43
Ethiopian	61	0.44	South African	5	0.04
Filipino	20	0.14	Sudanese	8	0.06
Guatemalan	7	0.05	Thai	13	0.09
Hmong	51	0.37	Tibetan	4	0.03
Honduran	4	0.03	Ukrainian	16	0.11
Indian	57	0.41	Vietnamese	56	0.4
Indonesian	1	0.01	native American/American Indian	13	0.09
Iranian	6	0.04			

**eTable 2. Records Review Instrument**

**Data Dictionary Codebook**

02/24/2023 12:42

#	Variable / Field Name	Field Label <i>Field Note</i>	Field Attributes (Field Type, Validation, Choices, Calculations, etc.)										
Instrument: <b>Encounter Information</b> (encounter_information)													
1	[mrn]	MRN	text, Identifier										
2	[hospital_id]	Hospital ID	text										
3	[department_name]	Department (at time of prediction)	text										
4	[time0]	Admission Datetime <i>time0 is same as hosp_admsn_time_1 in acute datamart for these patients</i>	text (datetime_mdy)										
5	[hosp_disch_time_1]	Discharge Datetime	text (datetime_mdy)										
6	[score_dttm]	Prediction Datetime	text (datetime_mdy)										
7	[review_window_end]	38 hours after prediction	text (datetime_seconds_mdy)										
8	[encounter_information_complete]	Section Header: <i>Form Status</i> Complete?	dropdown <table border="1"> <tr><td>0</td><td>Incomplete</td></tr> <tr><td>1</td><td>Unverified</td></tr> <tr><td>2</td><td>Complete</td></tr> </table>	0	Incomplete	1	Unverified	2	Complete				
0	Incomplete												
1	Unverified												
2	Complete												
Instrument: <b>To Do: Deterioration Review</b> (to_do_deterioration_review)													
9	[reviewer]	Who is performing this chart review?	dropdown, Required <table border="1"> <tr><td>1</td><td>Abhinab Kc</td></tr> <tr><td>2</td><td>Adarsh Ravishankar</td></tr> <tr><td>3</td><td>Bronwyn Southwell</td></tr> <tr><td>4</td><td>Tom Byrd</td></tr> <tr><td>5</td><td>Travis Tran</td></tr> </table>	1	Abhinab Kc	2	Adarsh Ravishankar	3	Bronwyn Southwell	4	Tom Byrd	5	Travis Tran
1	Abhinab Kc												
2	Adarsh Ravishankar												
3	Bronwyn Southwell												
4	Tom Byrd												
5	Travis Tran												
10	[display_score_dttm]	Encounter details: MRN: [mrn] Admission: [time0] Discharge: [hosp_disch_time_1] PREDICTION WINDOW for chart review: [score_dttm] to [review_window_end]	descriptive										
11	[reason_for_admission]	Brief overview of admission (e.g., "admitted from nursing home w/ fall and hip fx found to have sepsis which was treated but required ICU transfer, eventually discharged home")	notes, Required										
12	[code_status]	Section Header: <i>Code Status</i> Did patient have a code status of "DNR/DNI" any time during the prediction window?	yesno, Required <table border="1"> <tr><td>1</td><td>Yes</td></tr> <tr><td>0</td><td>No</td></tr> </table>	1	Yes	0	No						
1	Yes												
0	No												
13	[code_status_intubation] Show the field ONLY if: [code_status] = '1'	Would the patient have been intubated during the prediction window if their code status had been "FULL CODE"?	radio, Required <table border="1"> <tr><td>1</td><td>Most likely</td></tr> <tr><td>2</td><td>Unclear</td></tr> <tr><td>3</td><td>Unlikely</td></tr> </table>	1	Most likely	2	Unclear	3	Unlikely				
1	Most likely												
2	Unclear												
3	Unlikely												
14	[code_status_comments]	Comments regarding patient's code status during the prediction window and its effect on clinicians' treatment of the patient's deterioration (e.g., would patient have been transferred to the ICU if they were not DNR/DNI status?)	notes										
15	[outcome_mortality]	Section Header: <i>Mortality</i> Did patient die during the prediction window?	yesno, Required <table border="1"> <tr><td>1</td><td>Yes</td></tr> <tr><td>0</td><td>No</td></tr> </table>	1	Yes	0	No						
1	Yes												
0	No												
16	[mortality_comfort] Show the field ONLY if: [outcome_mortality] = '1'	Was patient on comfort care and/or inpatient hospice at time of death?	yesno, Required <table border="1"> <tr><td>1</td><td>Yes</td></tr> <tr><td>0</td><td>No</td></tr> </table>	1	Yes	0	No						
1	Yes												
0	No												



17	[mortality_datetime] Show the field ONLY if: [outcome_mortality] = '1'	Time of death on death certificate	text (datetime_mdy), Required										
18	[mortality_location] Show the field ONLY if: [outcome_mortality] = '1'	Patient location at time of death (e.g. ED, medical floor, surgical floor, inpatient hospice, ICU)	text, Required										
19	[mortality_reason] Show the field ONLY if: [outcome_mortality] = '1'	Cause of death from death certificate	text, Required										
20	[mortality_prevent] Show the field ONLY if: [outcome_mortality] = '1' and [mortality_comfort] = '0'	Was death preventable?	radio, Required <table border="1"> <tr><td>1</td><td>Clearly preventable</td></tr> <tr><td>2</td><td>Likely preventable</td></tr> <tr><td>3</td><td>Unknown</td></tr> <tr><td>4</td><td>Unlikely preventable</td></tr> <tr><td>5</td><td>Clearly not preventable</td></tr> </table>	1	Clearly preventable	2	Likely preventable	3	Unknown	4	Unlikely preventable	5	Clearly not preventable
1	Clearly preventable												
2	Likely preventable												
3	Unknown												
4	Unlikely preventable												
5	Clearly not preventable												
21	[mortality_comments] Show the field ONLY if: [outcome_mortality] = '1'	Comments on preventability of death	notes										
22	[outcome_icu]	Section Header: <i>ICU Transfer</i> Was patient transferred to ICU during the prediction window?	radio, Required <table border="1"> <tr><td>1</td><td>Yes</td></tr> <tr><td>2</td><td>No</td></tr> <tr><td>3</td><td>Already in ICU</td></tr> </table>	1	Yes	2	No	3	Already in ICU				
1	Yes												
2	No												
3	Already in ICU												
23	[icu_from] Show the field ONLY if: [outcome_icu] = '1'	Where was patient transferred from (e.g. PACU, medicine service, ED)	text, Required										
24	[icu_to] Show the field ONLY if: [outcome_icu] = '1'	ICU patient was transferred to (e.g. MICU, SICU, etc.)	text, Required										
25	[icu_reason] Show the field ONLY if: [outcome_icu] = '1'	Reason for ICU transfer	notes, Required										
26	[icu_prevent] Show the field ONLY if: [outcome_icu] = '1'	Was ICU transfer preventable?	radio, Required <table border="1"> <tr><td>1</td><td>Clearly preventable</td></tr> <tr><td>2</td><td>Likely preventable</td></tr> <tr><td>3</td><td>Unknown</td></tr> <tr><td>4</td><td>Unlikely preventable</td></tr> <tr><td>5</td><td>Clearly not preventable</td></tr> </table>	1	Clearly preventable	2	Likely preventable	3	Unknown	4	Unlikely preventable	5	Clearly not preventable
1	Clearly preventable												
2	Likely preventable												
3	Unknown												
4	Unlikely preventable												
5	Clearly not preventable												
27	[icu_comments] Show the field ONLY if: [outcome_icu] = '1'	Comments on preventability of ICU transfer	notes										
28	[outcome_vent]	Section Header: <i>Mechanical Ventilation</i> Was patient intubated during the prediction window?	radio, Required <table border="1"> <tr><td>1</td><td>Yes</td></tr> <tr><td>2</td><td>No</td></tr> <tr><td>3</td><td>Already mechanically ventilated</td></tr> </table>	1	Yes	2	No	3	Already mechanically ventilated				
1	Yes												
2	No												
3	Already mechanically ventilated												
29	[vent_location] Show the field ONLY if: [outcome_vent] = '1'	Patient location at time of intubation (e.g. ED, medical floor, surgical floor, ICU)	text, Required										
30	[vent_reason] Show the field ONLY if: [outcome_vent] = '1'	Reason for intubation	notes, Required										

31	[vent_prevent] Show the field ONLY if: [outcome_vent] = '1'	Was intubation preventable?	radio, Required 1 Clearly preventable 2 Likely preventable 3 Unknown 4 Unlikely preventable 5 Clearly not preventable
32	[vent_comments] Show the field ONLY if: [outcome_vent] = '1'	Comments on preventability of intubation	notes
33	[outcome_arrest]	Section Header: <i>Cardiac Arrest</i> Did patient have a cardiac arrest during the prediction window?	yesno, Required 1 Yes 0 No
34	[arrest_datetime] Show the field ONLY if: [outcome_arrest] = '1'	Time of cardiac arrest (from scanned code blue document)	text (datetime_mdy), Required
35	[arrest_location] Show the field ONLY if: [outcome_arrest] = '1'	Patient location at time of arrest (e.g. ED, medical floor, surgical floor, ICU)	text, Required
36	[arrest_reason] Show the field ONLY if: [outcome_arrest] = '1'	Suspected cause of cardiac arrest	text, Required
37	[arrest_prevent] Show the field ONLY if: [outcome_arrest] = '1'	Was cardiac arrest preventable?	radio, Required 1 Clearly preventable 2 Likely preventable 3 Unknown 4 Unlikely preventable 5 Clearly not preventable
38	[arrest_comments] Show the field ONLY if: [outcome_arrest] = '1'	Comments on preventability of cardiac arrest	notes
39	[outcome_rrt]	Section Header: <i>Rapid Response Team (RRT) Activation - RRT activation = bedside assessment of patient by primary or covering MD or APP, ICU nurse, and respiratory therapist. There may be a specific RRT note in the chart if RRT was activated.</i> Was the rapid response team (RRT) activated during the prediction window?	yesno, Required 1 Yes 0 No
40	[rrt_datetime] Show the field ONLY if: [outcome_rrt] = '1'	What time was RRT activated?	text (datetime_mdy)
41	[rrt_comments] Show the field ONLY if: [outcome_rrt] = '1'	Comments on the effects of RRT activation on patient's trajectory	notes
42	[covid_status]	Section Header: <i>COVID Status</i> Was patient suspected or confirmed to be COVID positive during the prediction window?	yesno, Required 1 Yes 0 No
43	[covid_cause] Show the field ONLY if: ([outcome_mortality] = '1' or [outcome_icu] = '1' or [outcome_vent] = '1' or [outcome_arrest] = '1' or [outcome_rrt] = '1') and ([covid_status] = '1')	Was COVID the underlying cause of death, ICU transfer, cardiac arrest, mechanical ventilation, or rapid response team activation during the prediction window? <i>if multiple of these occurred (e.g. ICU transfer then ventilated), only consider the first event (ICU transfer in this example)</i>	radio, Required 1 Yes 2 No 3 Unclear

44	[outcome_sepsis]	<p>Section Header: <i>Sepsis Presence</i></p> <p>Was bacterial sepsis newly suspected or treated during the prediction window? (Exclude sepsis exclusively from COVID i.e. no antibacterial treatment given)</p> <p><i>yes if "sepsis" or "suspected sepsis" listed as a problem in clinical note(s) and treatment plan included antibiotics</i></p>	<p>radio, Required</p> <table border="1"> <tr><td>1</td><td>Yes</td></tr> <tr><td>2</td><td>No</td></tr> <tr><td>3</td><td>Sepsis already suspected or being treated</td></tr> </table>	1	Yes	2	No	3	Sepsis already suspected or being treated
1	Yes								
2	No								
3	Sepsis already suspected or being treated								
45	[sepsis_datetime] Show the field ONLY if: [outcome_sepsis] = '1'	<p>Time of suspected sepsis or beginning of sepsis treatment</p> <p><i>could be first antibiotic administration or time of first note mentioning sepsis</i></p>	text (datetime_mdy), Required						
46	[sepsis_cause] Show the field ONLY if: ([outcome_mortality] = '1' or [outcome_icu] = '1' or [outcome_vent] = '1' or [outcome_arrest] = '1' or [outcome_rrt] = '1') and ([outcome_sepsis] = '1' or [outcome_sepsis] = '3')	<p>Was sepsis the underlying cause of death, ICU transfer, cardiac arrest, mechanical ventilation, or rapid response team activation during the prediction window?</p> <p><i>if multiple of these occurred (e.g. ICU transfer then ventilated), only consider the first event (ICU transfer in this example)</i></p>	<p>radio, Required</p> <table border="1"> <tr><td>1</td><td>Yes</td></tr> <tr><td>2</td><td>No</td></tr> <tr><td>3</td><td>Unclear</td></tr> </table>	1	Yes	2	No	3	Unclear
1	Yes								
2	No								
3	Unclear								
47	[final_comments]	<p>Section Header: <i>Additional Comments</i></p> <p>Any additional comments about this case</p>	notes						
48	[to_do_deterioration_review_complete]	<p>Section Header: <i>Form Status</i></p> <p>Complete?</p>	<p>dropdown</p> <table border="1"> <tr><td>0</td><td>Incomplete</td></tr> <tr><td>1</td><td>Unverified</td></tr> <tr><td>2</td><td>Complete</td></tr> </table>	0	Incomplete	1	Unverified	2	Complete
0	Incomplete								
1	Unverified								
2	Complete								

## eReferences

1. Harris PA, Taylor R, Minor BL, et al. The REDCap consortium: Building an international community of software platform partners. *Journal of Biomedical Informatics*. 2019;95:103208. doi:10.1016/j.jbi.2019.103208
2. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics*. 2009;42(2):377-381. doi:10.1016/j.jbi.2008.08.010
3. van Galen LS, Struik PW, Driesen BEJM, et al. Delayed Recognition of Deterioration of Patients in General Wards Is Mostly Caused by Human Related Monitoring Failures: A Root Cause Analysis of Unplanned ICU Admissions. *PLoS One*. 2016;11(8):e0161393. doi:10.1371/journal.pone.0161393