Online Data Supplement

Predicting Intensive Care Unit Readmission with Machine Learning Using Electronic Health Record Data

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Table E1: Variables Utilized in Full and Physiologic Models

Variable Category	Variable	How Variable Was Modeled
Patient Characteristics	Admission Source prior to ICU admission	Categorical
	Admitted to Medical ICU	Binary
	Age***, Length of Stay in the ICU (hours), Time of ICU Discharge (24-hour military time), Time of ICU Discharge (24-hour military time)	Continuous
Vital Signs*	Pulse (current, 24-hour maximum, 24-hour slope), Diastolic Blood Pressure (current, 24-hour minimum, 24-hour slope), Systolic Blood Pressure (current, 24-hour minimum, 24-hour slope), Respiratory Rate (current, 24-hour maximum, 24-hour SD), Oxygen Saturation (current, 24-hour minimum), Fraction of Inspired Oxygen (current, 24-hour maximum), SpO2/FiO2 (SF) ratio (current. 24-hour slope), Glasgow Coma Scale (current), Urine Output (24-hour sum)	Continuous
Laboratory Results*	Sodium (current), Potassium (current), Bicarbonate (current), Creatinine (current) Creatinine (maximum during ICU admission), Blood Urea Nitrogen (current), Glucose (current), White Blood Cell (current), Platelet (current), Hemoglobin (current, minimum during ICU admission), Total Bilirubin (current), Aspartate aminotransferase (current), Alanine aminotransferase (current), INR (current), PTT (current), BUN/Cr Ratio(current), Ketones (current. maximum during ICU admission), Lactic Acid (current, maximum during ICU admission), Troponin (current, maximum during ICU admission), pH (current. minimum during ICU admission), PaO2(current, minimum during ICU admission), PaCO2 (current, maximum during ICU admission), Change from last collected value of Creatinine, Change from last collected value of BUN, Change from last collected value of BUN/Cr ratio	Continuous
ICU Interventions	Ventilator (during ICU admission, during last 48 hours of ICU admission), Dialysis (during ICU admission, during last 48 hours of ICU admission), Bi-level Positive Airway Pressure (during ICU admission, during last 48 hours ICU admission), High Flow Nasal Cannula (during ICU admission, during last 48 hours ICU admission), Continuous positive airway pressure (during ICU admission), Cardiac arrest any time prior to ICU discharge, Surgery done in OR any time prior to ICU discharge, Left ventricular assist device, Foley present at time of ICU discharge	Binary
	Transfusions with pRBC (during ICU admission). Transfusions with FFP (during ICU admission), Transfusions of Platelets (during ICU admission), Transfusions of Cryoprecipitate (during ICU admission), Number of ICU Interventions Performed (during last 48 hours of ICU admission)	Continuous
Medications	IV Sedation (during ICU admission, during last 48 hours of ICU admission), IV Benzodiazepines (during last 48 hours of ICU admission), Vasoactive (during ICU admission), Inotrope (during ICU admission, during last 48 hours of ICU admission), Nebulized albuterol (during ICU admission), IV Anti-psychotics (during ICU admission, during last 48 hours of ICU admission), IV steroids (during ICU admission, during last 48 hours of ICU admission), PO steroids (during ICU admission, during last 48 hours of ICU admission),	Binary

	PO immunosuppression (during ICU admission, during last 48 hours of ICU admission) IV immunosuppression (during ICU admission, during last 48 hours of ICU admission), IV Insulin drip (during ICU admission), IV diuretic (during last 48 hours of ICU admission), IV AV-Nodal blocking agent (during last 48 hours prior to discharge), IV antiarrhythmic (during last 48 hours of prior to ICU discharge), IV anticoagulation (during last 48 hours prior to ICU discharge), PO anticoagulation (during last 48 hours prior to ICU discharge), Lactulose (during ICU admission, during last 48 hours of ICU admission), IV antibiotics (during ICU admission),, PO antibiotics (during ICU admission), IV anti-fungal (during ICU admission), PO anti-fungal (during ICU admission), IV anti-viral (during ICU admission), PO anti-viral (during ICU admission)	
	Number of vasoactive medication (during ICU admission), Nebulized albuterol treatments (during last 48 hours of ICU admission), Number of anti-infective medications (during last 48 hours of ICU admission), Number of crystalloid bolus (during last 48 hours of ICU admission), Number of colloid bolus (during last 48 hour of ICU admission), Number of medications categories patient received (during last 48 hour of ICU admission)	Continuous
Nursing Assessments	Morse Mental Status (current), Morse Gait (current), Morse Score (current), Braden Activity (current), Braden Friction Scale (current). Braden Mobility Scale (current). Braden Sensory Scale (current), Braden Scale(current), Nursing Abdominal Physical Exam During Last 48 hours of ICU admission (ascites, abdominal distension, firm abdomen, tender abdomen, rigid abdomen, gravid), Telemetry Rhythm Documented by Nursing Over Last 48 hours of ICU Admission (atrial fibrillation, atrial flutter, paced, SVT, VT, Asystole, Heart Block (I, II, III), junctional)	Binary
	Number of Documented Nurse Oral/Nasal Suctioning Events (during last 48 hours of ICU admission)	Continuous
Diagnostic Tests*	ECG, TTE, Chest X-ray, Abdominal X-ray, Right Upper Quadrant Ultrasound, CT Head, CT Chest, CT Neck, CT Abdomen/Pelvis, CT Chest/Abdomen/Pelvis, Blood Culture, Positive Blood Culture	Binary
	Number of Diagnostic Tests Ordered (during last 48 hours of ICU admission)	Continuous
Elixhauser ICD-9 Code Category**	Congestive heart failure, Valvular disease, Pulmonary circulation disorders. Peripheral Vascular Disease, Hypertension (complicated), Hypertension (uncomplicated), Paralysis. Other neurological disorders. Chronic pulmonary disease. Diabetes (uncomplicated). Diabetes (complicated), Hypothyroidism. Renal failure, Liver disease, Peptic ulcer disease excluding bleeding, AIDS. Lymphoma. Metastatic cancer, Solid tumor without metastasis. Rheumatoid arthritis/ collagen vascular diseases, Coagulopathy, Obesity, Blood loss anemia, Deficiency anemia. Alcohol abuse. Drug abuse, Psychoses. Depression	Binary
	Number of Elixhauser Comorbidities	Continuous

*All variables in the diagnostic tests category were binary variables that captured if a specific diagnostic test was ordered or resulted in the last 48 prior to ICU discharge

**ICD-9 data was only used for patients who had prior admissions to our hospital not for the index admission.

***Variables used in the physiologic model

Abbreviations: ICU=Intensive Care Unit, SpO2=pulse oximeter saturation; FiO2=fraction of inspired oxygen, PaO2=Arterial oxygen partial pressure, PaCO2=Arterial carbon dioxide partial pressure, Bun/Cr=Blood Urea Nitrogen/Creatinine, INR= International Normalized Units, PTT= Partial thromboplastin time, pRBC=Packed Red Blood Cells, FFP=Fresh Frozen Plasma, IV=Intravenous, PO=Oral, ECG=Electrocardiogram, TTE=Transthoracic Echocardiography, CT=Computed Tomography, OR=Operating Room, AIDS= Acquired Immune Deficiency Syndrome

Table E2: Comparison of patient treatments and interventions in the intensive care unit by readmission status in the University of Chicago cohort. *

	Readmitted, n (%) N=2,834	Not readmitted, n (%) N=22,051	p-value
Dialysis, yes	443 (16)	1,648 (7)	<0.0001
Vasopressors, yes	578 (20)	2,803 (13)	<0.0001
Intravenous sedation, yes	785 (28)	4,571 (21)	<0.0001
Noninvasive Ventilation, yes	282 (10)	1,597 (7)	<0.0001
High flow nasal cannula, yes	86 (3)	386 (2)	<0.0001
Vasopressors, yes	578 (20)	2,803 (13)	<0.0001
Cardiac arrest at any time prior to ICU discharge, yes	44 (2)	4,571 (21)	<0.0001
Surgery at any time prior to ICU discharge, yes	879 (31)	8,448 (38)	<0.0001
Number of Current Anti-Infectives* *at time of ICU discharge			<0.0001
0	821 (29)	8,722 (40)	
1-2	1.001 (35)	9,017 (41)	
3+	1,012 (36)	4,312 (20)	
Diuretics in last 48 hrs, yes	797 (28)	4,897 (22)	<0.0001
Transfusion of packed red bloods cells			<0.0001
None	2,467 (87)	20,524 (93)	
1-5	299 (11)	1,249 (6)	
5-9	56 (2)	206 (1)	

10+	12 (0)	72 (0)	
Transfusion of platelets			<0.0001
None	2,364 (83)	20,201 (92)	
1-5	359 (13)	1,647 (7)	
5-9	65 (2)	130 (1)	
10+	46 (2)	73 (0)	
Transfusion of fresh frozen plasma			<0.0001
None	2,235(79)	19,411 (88)	
1-5	496 (18)	2,342 (11)	
5-9	62 (2)	222 (1)	
10+	41 (1)	76 (0)	

*Data presented as n (%) unless otherwise noted.

**Anti-infectives were defined broadly as treatment dose antibiotic, antiviral, and antifungals medications.

Abbreviations: ICU= Intensive Care Unit

Table E3: Risk score comparisons of sensitivity, specificity, and area under the receiver operating characteristic curve (AUC) for the different readmission models to the newly derived machine learning score in the internal validation cohort.

Model Cut-off	Sensitivity (%)	Specificity (%)	AUC
MEWS			0.59 (0.57-0.62)
3	35	78	
4	16	92	
5	8	98	
SWIFT			0.65 (0.63- 0.67)
12	47	75	
16	22	90	
20	15	95	
Derived (GBM) Score			0.76 (0.75-0.78)
0.46	69	65	
0.54	65	75	
0.65	49	85	
0.71	38	90	
0.77	28	95	

Abbreviations: SWIFT = Stability and Workload Index for Transfer; MEWS = Modified Early Warning Score; AUC=Areas Under the Receiver Operating Characteristic Curve

Table E4: Area under the curve (AUC) comparisons using stepwise addition of variable categories to predict ICU readmission in the internal validation cohort*.

Variable Categories	AUC
Laboratory	0.72
Laboratory + Vitals	0.74
Laboratory + Nursing	0.74
Laboratory + Nursing + Vitals	0.75
Laboratory + Nursing + Vitals + Medications	0.75
Laboratory + Nursing + Vitals + Medications + Demographics	0.75
Laboratory + Nursing + Vitals + Medications + Demographics + ICU Interventions	0.76
Laboratory + Nursing + Vitals + Medications + Demographics + ICU Interventions + Diagnostic Tests	0.76
Laboratory + Nursing + Vitals + Medications + Demographics + ICU Interventions + Diagnostic Tests + Medical Comorbidities	0.76

*Readmission at any time after ICU discharge

Abbreviations: AUC= area under the receiver operating characteristic curve (AUC)