

## **Supplementary materials**

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**Supplementary Table 1.** ICD-9-CM and ICD-10-CM codes for cardiac arrest and fatal ventricular arrhythmia

<b>ICD-9-CM</b>	<b>Description</b>	<b>ICD-10-CM</b>	<b>Description</b>
<b>Cardiac arrest</b>			
798	Sudden death cause unknown	R99	III-defined and unknown cause of mortality
798.1	Instantaneous death	I46	Cardiac arrest
798.2	Death occurring in less than 24 hours from onset of symptoms, not otherwise explained	I46.2	Cardiac arrest due to underlying cardiac condition
798.9	Unattended death	I46.8	Cardiac arrest due to other underlying condition
799.9	Other unknown and unspecified cause of morbidity and mortality	I46.9	Cardiac arrest, cause unspecified
427.5	Cardiac arrest		
<b>Fatal ventricular arrhythmia</b>			
427.1	Paroxysmal ventricular tachycardia; ventricular tachycardia	I47.2	Ventricular tachycardia
427.4	Ventricular fibrillation and flutter	I49.0	Ventricular fibrillation and flutter
427.41	Ventricular fibrillation	I49.01	Ventricular fibrillation
427.42	Ventricular flutter	I49.02	Ventricular flutter

**Abbreviations:** ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; ICD-10-CM, International Classification of Diseases, Tenth Revision, Clinical Modification.

**Supplementary Table 2.** Keywords used for screening ED physicians' notes

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ACLS

AED

Asystole

cardiac arrest

CPR, CPCR, cardiac massage (exclude: CPR room)

death

defibrillation

no breath, no spontaneous breath, no spontaneous respiration

no pulse, no palpable pulse, no spontaneous pulse, no heart beat

no response

OHCA

PEA, pulseless electrical activity

ROSC

standstill

VF, ventricular fibrillation, VFIB

VT, ventricular tachycardia

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**Abbreviations:** ED: emergency department.

**Supplementary Table 3.** Performance of algorithms for all patients (n = 985526)

Alg	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	PPV (%) (95% CI)	NPV (%) (95% CI)	Kappa (95% CI)
<b>A</b>	77.1 (75.4–78.8)	100.0 (100.0–100.0)	96.4 (95.5–97.2)	99.9 (99.9–99.9)	0.857 (0.846–0.868)
<b>B</b>	77.8 (76.1–79.4)	100.0 (100.0–100.0)	92.1 (90.8–93.2)	99.9 (99.9–99.9)	0.843 (0.831–0.854)
<b>C</b>	89.5 (88.2–90.7)	100.0 (100.0–100.0)	90.6 (89.4–91.8)	100.0 (100.0–100.0)	<b>0.900 (0.891–0.909)</b>
<b>D</b>	90.1 (88.9–91.3)	100.0 (99.9–100.0)	81.9 (80.4–83.4)	100.0 (100.0–100.0)	0.858 (0.848–0.868)
<b>E</b>	91.5 (90.3–92.6)	100.0 (100.0–100.0)	86.2 (84.8–87.5)	100.0 (100.0–100.0)	0.887 (0.878–0.897)
<b>F</b>	92.0 (90.8–93.0)	99.9 (99.9–99.9)	73.8 (72.2–75.4)	100.0 (100.0–100.0)	0.819 (0.807–0.830)
<b>G</b>	71.9 (70.1–73.7)	100.0 (100.0–100.0)	98.0 (97.2–98.6)	99.9 (99.9–99.9)	0.829 (0.817–0.841)
<b>H</b>	72.5 (70.7–74.3)	100.0 (100.0–100.0)	96.9 (96.0–97.6)	99.9 (99.9–99.9)	0.829 (0.817–0.841)
<b>I</b>	83.6 (82.1–85.1)	100.0 (100.0–100.0)	95.5 (94.6–96.4)	100.0 (100.0–100.0)	0.892 (0.882–0.901)
<b>J</b>	84.2 (82.7–85.6)	100.0 (100.0–100.0)	93.4 (92.3–94.4)	100.0 (100.0–100.0)	0.885 (0.876–0.895)
<b>K</b>	85.6 (84.1–87.0)	100.0 (100.0–100.0)	93.6 (92.5–94.5)	100.0 (100.0–100.0)	<b>0.894 (0.884–0.903)</b>
<b>L</b>	86.0 (84.6–87.4)	100.0 (100.0–100.0)	89.7 (88.4–90.9)	100.0 (100.0–100.0)	0.878 (0.868–0.888)
<b>M</b>	50.8 (48.8–52.8)	100.0 (100.0–100.0)	98.2 (97.4–98.9)	99.9 (99.9–99.9)	0.669 (0.652–0.687)
<b>N</b>	51.3 (49.3–53.3)	100.0 (100.0–100.0)	97.3 (96.2–98.1)	99.9 (99.9–99.9)	0.671 (0.654–0.689)
<b>O</b>	60.2 (58.2–62.1)	100.0 (100.0–100.0)	92.8 (91.4–94.1)	99.9 (99.9–99.9)	0.730 (0.714–0.745)
<b>P</b>	60.5 (58.5–62.5)	100.0 (100.0–100.0)	90.2 (88.6–91.6)	99.9 (99.9–99.9)	0.724 (0.708–0.739)
<b>Q</b>	61.8 (59.8–63.7)	100.0 (100.0–100.0)	88.4 (86.8–89.9)	99.9 (99.9–99.9)	0.727 (0.712–0.742)

<b>R</b>	62.0 (60.0–63.9)	100.0 (100.0–100.0)	83.9 (82.1–85.6)	99.9 (99.9–99.9)	0.712 (0.697–0.728)
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**Notes:** The top two kappa values are in bold face type.

**Abbreviations:** Alg, algorithm; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

**Supplementary Table 4.** Performance of algorithms stratified by ICD coding system

Subgroup	Alg	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	PPV (%) (95% CI)	NPV (%) (95% CI)	Kappa (95% CI)
ICD-9-CM (2010–2015) (n = 561331)	A	79.4 (77.1–81.5)	100.0 (100.0–100.0)	96.6 (95.3–97.5)	99.9 (99.9–100.0)	0.871 (0.857–0.885)
	B	79.7 (77.5–81.8)	100.0 (100.0–100.0)	91.9 (90.2–93.4)	100.0 (99.9–100.0)	0.854 (0.839–0.868)
	C	90.8 (89.2–92.3)	100.0 (100.0–100.0)	92.3 (90.7–93.6)	100.0 (100.0–100.0)	<b>0.915 (0.904–0.926)</b>
	D	91.4 (89.8–92.8)	100.0 (99.9–100.0)	82.9 (80.9–84.8)	100.0 (100.0–100.0)	0.869 (0.856–0.882)
	E	92.1 (90.6–93.5)	100.0 (100.0–100.0)	88.9 (87.1–90.5)	100.0 (100.0–100.0)	0.905 (0.893–0.916)
	F	92.6 (91.1–93.9)	99.9 (99.9–99.9)	76.1 (74.0–78.1)	100.0 (100.0–100.0)	0.835 (0.821–0.849)
	G	71.5 (69.0–73.8)	100.0 (100.0–100.0)	98.6 (97.7–99.2)	99.9 (99.9–99.9)	0.828 (0.812–0.845)
	H	71.8 (69.4–74.2)	100.0 (100.0–100.0)	97.8 (96.7–98.6)	99.9 (99.9–99.9)	0.828 (0.812–0.844)
	I	82.2 (80.1–84.2)	100.0 (100.0–100.0)	96.8 (95.7–97.8)	100.0 (100.0–100.0)	0.889 (0.876–0.902)
	J	82.7 (80.6–84.7)	100.0 (100.0–100.0)	95.2 (93.9–96.4)	100.0 (100.0–100.0)	0.885 (0.872–0.898)
	K	83.5 (81.4–85.4)	100.0 (100.0–100.0)	95.5 (94.2–96.6)	100.0 (100.0–100.0)	0.891 (0.878–0.903)
	L	83.9 (81.9–85.8)	100.0 (100.0–100.0)	92.1 (90.4–93.5)	100.0 (100.0–100.0)	0.878 (0.864–0.891)
ICD-10-CM (2016–2020) (n = 424195)	A	74.1 (71.4–76.8)	100.0 (100.0–100.0)	96.3 (94.7–97.5)	99.9 (99.9–99.9)	0.837 (0.819–0.856)
	B	75.2 (72.5–77.8)	100.0 (100.0–100.0)	92.4 (90.4–94.1)	99.9 (99.9–99.9)	0.829 (0.810–0.847)
	C	87.8 (85.6–89.7)	100.0 (100.0–100.0)	88.5 (86.4–90.3)	100.0 (100.0–100.0)	0.881 (0.866–0.896)
	D	88.5 (86.4–90.3)	99.9 (99.9–100.0)	80.6 (78.2–82.9)	100.0 (100.0–100.0)	0.843 (0.827–0.859)
	E	90.7 (88.8–92.4)	100.0 (99.9–100.0)	82.8 (80.5–84.9)	100.0 (100.0–100.0)	0.865 (0.850–0.881)
	F	91.1 (89.2–92.8)	99.9 (99.9–99.9)	71.0 (68.5–73.4)	100.0 (100.0–100.0)	0.798 (0.780–0.815)
	G	72.5 (69.7–75.2)	100.0 (100.0–100.0)	97.2 (95.8–98.2)	99.9 (99.9–99.9)	0.830 (0.812–0.849)
	H	73.5 (70.7–76.1)	100.0 (100.0–100.0)	95.7 (94.0–97.0)	99.9 (99.9–99.9)	0.831 (0.812–0.849)
	I	85.5 (83.2–87.6)	100.0 (100.0–100.0)	93.9 (92.2–95.4)	100.0 (100.0–100.0)	0.895 (0.881–0.909)
	J	86.2 (83.9–88.2)	100.0 (100.0–100.0)	91.2 (89.3–92.9)	100.0 (100.0–100.0)	0.886 (0.871–0.900)
	K	88.4 (86.3–90.2)	100.0 (100.0–100.0)	91.2 (89.3–92.9)	100.0 (100.0–100.0)	<b>0.898 (0.884–0.911)</b>

<b>L</b>	88.7 (86.7–90.6)	100.0 (100.0–100.0)	87.0 (84.8–89.0)	100.0 (100.0–100.0)	0.878 (0.864–0.893)
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**Notes:** The highest kappa for each subgroup is in bold face type.

**Abbreviations:** Alg, algorithm; CI, confidence interval; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; ICD-10-CM, International Classification of Diseases, Tenth Revision, Clinical Modification; PPV, positive predictive value; NPV, negative predictive value.

**Supplementary Table 5.** Performance of algorithms stratified by age and type of claims

Subgroup	Alg	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	PPV (%) (95% CI)	NPV (%) (95% CI)	Kappa (95% CI)
Adult patients (≥18 y/o) (n=731993)	A	77.3 (75.6–79.0)	100.0 (100.0–100.0)	97.1 (96.2–97.8)	99.9 (99.9–99.9)	0.860 (0.849–0.871)
	B	78.0 (76.2–79.6)	100.0 (100.0–100.0)	93.1 (91.9–94.1)	99.9 (99.9–99.9)	0.848 (0.837–0.859)
	C	89.6 (88.3–90.8)	100.0 (100.0–100.0)	91.0 (89.7–92.1)	100.0 (100.0–100.0)	<b>0.903 (0.894–0.912)</b>
	D	90.2 (89.0–91.4)	99.9 (99.9–99.9)	82.4 (80.9–83.9)	100.0 (100.0–100.0)	0.861 (0.851–0.871)
	E	91.7 (90.5–92.8)	100.0 (99.9–100.0)	86.5 (85.1–87.8)	100.0 (100.0–100.0)	0.890 (0.881–0.899)
	F	92.1 (91.0–93.2)	99.9 (99.9–99.9)	74.2 (72.5–75.7)	100.0 (100.0–100.0)	0.821 (0.810–0.832)
	G	72.1 (70.3–73.9)	100.0 (100.0–100.0)	97.9 (97.2–98.6)	99.9 (99.9–99.9)	0.830 (0.818–0.843)
	H	72.7 (70.9–74.5)	100.0 (100.0–100.0)	97.1 (96.2–97.9)	99.9 (99.9–99.9)	0.831 (0.819–0.844)
	I	83.8 (82.3–85.3)	100.0 (100.0–100.0)	95.4 (94.5–96.3)	99.9 (99.9–100.0)	0.892 (0.883–0.902)
	J	84.4 (82.8–85.8)	100.0 (100.0–100.0)	93.6 (92.4–94.6)	99.9 (99.9–100.0)	0.887 (0.877–0.897)
	K	85.8 (84.4–87.2)	100.0 (100.0–100.0)	93.5 (92.4–94.5)	100.0 (99.9–100.0)	0.895 (0.885–0.904)
	L	86.2 (84.8–87.6)	100.0 (100.0–100.0)	89.8 (88.5–91.0)	100.0 (100.0–100.0)	0.880 (0.870–0.889)
Pediatric patients (<18 y/o)	A	69.1 (55.2–80.9)	100.0 (100.0–100.0)	73.1 (59.0–84.4)	100.0 (100.0–100.0)	0.710 (0.613–0.808)
	B	69.1 (55.2–80.9)	100.0 (100.0–100.0)	61.3 (48.1–73.4)	100.0 (100.0–100.0)	0.650 (0.549–0.750)
	C	83.6 (71.2–92.2)	100.0 (100.0–100.0)	76.7 (64.0–86.6)	100.0 (100.0–100.0)	0.800 (0.720–0.880)
	D	85.5 (73.3–93.5)	100.0 (100.0–100.0)	64.4 (52.3–75.3)	100.0 (100.0–100.0)	0.734 (0.648–0.820)
	E	83.6 (71.2–92.2)	100.0 (100.0–100.0)	71.9 (59.2–82.4)	100.0 (100.0–100.0)	0.773 (0.690–0.856)

(n = 253533)	F	85.0 (73.3–93.5)	100.0 (100.0–100.0)	61.0 (49.2–72.0)	100.0 (100.0–100.0)	0.712 (0.624–0.800)
	G	63.6 (49.6–76.2)	100.0 (100.0–100.0)	100.0 (90.0–100.0)	100.0 (100.0–100.0)	0.778 (0.683–0.873)
	H	63.6 (49.6–76.2)	100.0 (100.0–100.0)	85.4 (70.8–94.4)	100.0 (100.0–100.0)	0.729 (0.629–0.829)
	I	74.5 (61.0–85.3)	100.0 (100.0–100.0)	100.0 (91.4–100.0)	100.0 (100.0–100.0)	<b>0.854 (0.779–0.930)</b>
	J	76.4 (63.0–86.8)	100.0 (100.0–100.0)	87.5 (74.8–95.3)	100.0 (100.0–100.0)	0.816 (0.734–0.897)
	K	74.5 (61.0–85.3)	100.0 (100.0–100.0)	97.6 (87.4–99.9)	100.0 (100.0–100.0)	0.845 (0.768–0.923)
	L	76.4 (63.0–86.8)	100.0 (100.0–100.0)	85.7 (72.8–94.1)	100.0 (100.0–100.0)	0.808 (0.725–0.890)
Outpatient claims (n=803018)	A	87.4 (85.8–88.9)	100.0 (100.0–100.0)	97.8 (97.0–98.4)	100.0 (100.0–100.0)	0.923 (0.914–0.932)
	B	87.4 (85.8–88.9)	100.0 (100.0–100.0)	96.5 (95.5–97.3)	100.0 (100.0–100.0)	0.917 (0.908–0.926)
	C	90.8 (89.4–92.1)	100.0 (100.0–100.0)	96.4 (95.4–97.2)	100.0 (100.0–100.0)	<b>0.935 (0.927–0.943)</b>
	D	90.9 (89.5–92.2)	100.0 (100.0–100.0)	94.1 (93.0–95.2)	100.0 (100.0–100.0)	0.925 (0.916–0.934)
	E	91.2 (89.9–92.5)	100.0 (100.0–100.0)	95.9 (94.9–96.8)	100.0 (100.0–100.0)	0.935 (0.927–0.943)
	F	91.3 (90.0–92.6)	100.0 (100.0–100.0)	93.5 (92.2–94.5)	100.0 (100.0–100.0)	0.924 (0.915–0.932)
	G	81.2 (79.4–82.9)	100.0 (100.0–100.0)	98.9 (98.3–99.4)	100.0 (100.0–100.0)	0.892 (0.881–0.903)
	H	81.2 (79.4–82.9)	100.0 (100.0–100.0)	98.6 (97.9–99.1)	100.0 (100.0–100.0)	0.890 (0.879–0.901)
	I	84.3 (82.5–85.9)	100.0 (100.0–100.0)	98.1 (97.3–98.7)	100.0 (100.0–100.0)	0.906 (0.896–0.916)
	J	84.4 (82.7–86.0)	100.0 (100.0–100.0)	97.8 (96.9–98.4)	100.0 (100.0–100.0)	0.906 (0.895–0.916)
	K	84.6 (82.9–86.2)	100.0 (100.0–100.0)	98.0 (97.2–98.6)	100.0 (100.0–100.0)	0.908 (0.898–0.918)
	L	84.7 (83.0–86.3)	100.0 (100.0–100.0)	97.6 (96.7–98.3)	100.0 (100.0–100.0)	0.907 (0.897–0.917)

<b>Inpatient claims</b> <b>(n=182508)</b>	<b>A</b>	39.6 (35.4–43.9)	100.0 (100.0–100.0)	87.0 (82.0–91.0)	99.8 (99.8–99.8)	0.543 (0.500–0.586)
	<b>B</b>	42.6 (38.4–47.0)	99.9 (99.9–100.0)	68.8 (63.5–73.8)	99.8 (99.8–99.9)	0.526 (0.485–0.566)
	<b>C</b>	84.7 (81.3–87.7)	99.9 (99.9–99.9)	73.5 (69.7–77.0)	100.0 (100.0–100.0)	0.786 (0.760–0.813)
	<b>D</b>	87.2 (84.0–89.9)	99.8 (99.8–99.9)	54.9 (51.4–58.3)	100.0 (100.0–100.0)	0.672 (0.644–0.701)
	<b>E</b>	92.5 (89.9–94.6)	99.8 (99.8–99.9)	63.1 (59.6–66.5)	100.0 (100.0–100.0)	0.750 (0.723–0.776)
	<b>F</b>	94.3 (91.9–96.1)	99.6 (99.6–99.7)	42.4 (39.5–45.3)	100.0 (100.0–100.0)	0.583 (0.555–0.611)
	<b>G</b>	38.0 (33.9–42.4)	100.0 (100.0–100.0)	91.3 (86.7–94.7)	99.8 (99.8–99.8)	0.536 (0.493–0.580)
	<b>H</b>	40.9 (36.7–45.3)	100.0 (100.0–100.0)	85.9 (81.0–90.0)	99.8 (99.8–99.8)	0.554 (0.511–0.596)
	<b>I</b>	81.3 (77.6–84.5)	100.0 (100.0–100.0)	86.9 (83.6–89.8)	99.9 (99.9–100.0)	0.840 (0.815–0.864)
	<b>J</b>	83.6 (80.1–86.6)	99.9 (99.9–100.0)	80.3 (76.7–83.6)	100.0 (99.9–100.0)	0.819 (0.793–0.844)
	<b>K</b>	89.1 (86.1–91.6)	99.9 (99.9–100.0)	80.9 (77.5–84.0)	100.0 (100.0–100.0)	<b>0.848 (0.825–0.870)</b>
	<b>L</b>	90.6 (87.8–93.0)	99.9 (99.9–99.9)	70.4 (66.8–73.9)	100.0 (100.0–100.0)	0.792 (0.767–0.817)

**Notes:** The highest kappa for each subgroup is in bold face type.

**Abbreviations:** Alg, algorithm; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

**Supplementary Figure 1.** Confusion matrix analyzing algorithm performance against the gold standard.

**Abbreviations:** PPV, positive predictive value; NPV, negative predictive value; OHCA, out-of-hospital cardiac arrest.

		OHCAs ascertained by experts (Gold standard)	
		Positive	Negative
OHCAs identified by algorithms	Positive	True Positive (TP)	False Positive (FP)
	Negative	False Negative (FN)	True Negative (TN)

$$\text{Sensitivity} = \text{TP} / (\text{TP} + \text{FN})$$

$$\text{Specificity} = \text{TN} / (\text{TN} + \text{FP})$$

$$\text{PPV} = \text{TP} / (\text{TP} + \text{FP})$$

$$\text{NPV} = \text{TN} / (\text{TN} + \text{FN})$$