Supplementary

Table S1 Details on the architecture of each model, along with relevant comments

Study	Architecture[†]	Details and comments[‡]
(64)	N/A	Previously trained and validated algorithm by Attia, 2019; LVSD validated with echo; Superior to NT-proBNP (AUC: 0.80)
(21)	I-{CBReP}x6CBRe{DBReDr}x2So-O	Explicit "Temporal – spatial" architecture; LVSD validated with echo; Patients without diagnosed LVSD but positive for model-screening, had a 4-fold higher risk for future LVSD
(22)	I-{{{BRCBC}//{CP}}x3Dr}x3CBReDrDSo-O	Explicit "Temporal – spatial" architecture; Future AF by current SR ECG; Combined AF/Atrial flutter vs. other labels; AF validated by trained personnel
(58)	I-{C//C//C}{SE}Cx2{SE}Cx4{SE}Cx6{SE}Cx4PDSi-O	{SE}: I-{PDReDSi}//{}-O; AF validated by expert cardiologists; Also two other experiments: AF vs. non-AF, AF vs. normal vs. non-AF
(30)	I-{CCP}x5GbABDSi-O	Adequate performance also for 476 patients with combined arrhythmias; Slightly worse for single-lead ECG
(29)	LSTM structure	Also compared against GRU and vanilla RNN models; No details about other blocks; LSTM seems superior to vanilla RNN and GRU alternatives; ACC is balanced (BACC); 549 ECGs, further segmented to 12,359 data points
(54)	I-DTW-DDSo-O	10 cluster centers by 40 typical samples; Superior to other traditional methods; Low training - High testing time
(31)	I-A{{CReBPDrCReBPDrA}//{GbBDrA}}BDrD-O	First detect MI (ACC=0.96), then locate it (ACC=0.63); Metrics for inter-patient analysis (intra-patient: ACC=0.99); Beat-based
(49)	WT - feature selection - SVM	Beat-based
(40)	I-{CRe//}x12C{CReBCReB}x3CBPDSo-O	Also compared against I-WT-PCAx4-3layerNN-O; Results slightly lower for hierarchical classification (WT-PCA-NN); 549 ECGs divided into 5,968 segments
(47)	I-{CBReP{Db}x3CBReP{Db}x3CBReP{Db}x3CBReP{Db}x3ALSo}//{{CBReP{Db}x3CBReP{Db}x3CBReP{Db}x3CBReP{Db}x3}//{CBReP{Db}x9}}-O	{Db}: I-{CBRe{{CBRe}//{ABRe}}-O; Complex, ensemble structure;
(41)	I-{CBP{Res}x4FDDrD}//2-DDrDDrDSi-O	{Res}: I-{CBCB}//{}Si-O; One module for irregularity and one for P detection (in parallel); Developed with internal data, validated on external data; Performance reported for PTB-XL
(28)	n.a.	Not provided; Copyrighted algorithms for each step (not provided); Validated on CSE
(48)	I-CPCP{Inc}x2P{Inc}x5P{Inc}x2P{G}x2DrSo-O	{Inc}: I-{CBR//CCBRe//CCBRe//PCBRe}-O; Also tested against external databases (custom set of 6,500 and PhysioNet set of 500 samples); Metrics from the external PhysioNet databank
(50)	WT - 228-feature selection (Relief) - KNN	Rule-based; Also compared against other classifiers (SVM, ANN, DA) with suboptimal results
(33)	I-{CBPCBPCBPP}//12-Lb//12-D-O	Beat-based
(34)	I-{{CBReP}x3DDrRe}//{Lb}-{DDrRe}x3So-O	Lb only for lead II
(65)	I-CBReP{CReP}x3DrDBReDrDSi-O	Superior to cardiologists' performance; Better results against lower resolution ECG images or fewer leads
(63)	n.a.	No details on how signals are segmented into 1 sec intervals
(35)	I-Lbx2DSo-O	
(59)	WT delineator (4 -level) - split - {CSP} - kNN	{CSP}: Custom trainable filter for extracting features; Beat-based; Training of the CSP filter (2-fold) and the kNN classifier (10-fold cross-validation); Train/test sets formed after WT
(37)	I-CP{Res}x3CAPDDSi-O	{Res}: I-{{{Sc}B}//{CB{Sc}BCB}Sw}-O; {Sc}: Custom module, similar to DWT; Dr added in between layers; Modified metric (CinC2020 guidelines)
(51)	WT - SVD - SVM	Segmented to beats to form frames; The ACC for detecting MI only is 0.953
(23)	I-{GA}//12ADSo-O	{GA} for every lead, then A for inter-lead mixing
(24)	I-{CReB{I}x4CReBP}//8{DRe}x3DSi-O	{I}: {CReB}//3P; Patients positive for algorithm result had a 7.2-fold higher risk for developing AF over 30 years; Downsized to 8 from 12 leads
(38)	I-CBRe{Res}x4DSi-O	{Res}: I-{{PC}//{CBReDrC}}{{BReDr}//{}}-O; No "normal" class is reported; Sigmoid activation to account for multi-labeled cases; Outperforms human evaluators (F1-score)
(25)	I-{{MB}Si{MB}P}//8-{{GbDr}//{Dr}}-ReDrABReDrDSi-O	{MB}: {{CReCRe}//{CReDr}}; Modified metric (CinC2020 guidelines); Downsized to 8 from 12 leads
(42)	I-{CP}x6So-O	

Table S1 (*continued*)

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Table S1 (*continued*)

Study	Architecture[†]	Details and comments[‡]
(55)	I-{CNN}-HMM-heuristic-GBM-O	{CNN}: CNN with C, B, D layers for delineation (features of ECG); HMM (Hidden Markov Model) and a heuristic used for optimizing the delineator; CNN finds meaningful segments (e.g.,: P wave) and features [725] which are "fed" to a GBM (Gradient Boosted Machine) classifier; CNN trained on 170 manually annotated ECGs
(52)	Phase alteration features (WT) - fuzzy kNN	
(53)	WT/FT - SVM	
(56)	I-FT/WT-CRePDDSo-O	Beat-based
(57)	WT/FT - NN	
(43)	I-{segm}-{C{{DB}BErCDrP}x3{DB}BReP}//10-DrFDSi-O	{segm}: Segmentation to 10 pieces of 10 sec each (with overlapping); {DB}: I-{{BReCDr}//{}}-{{BReCDr}//{}}-O
(44)	I-{Net1}//{Net2}//{Net3}-Ensemble-O	{Net1}, {Net2}, {Net3} represent 3 different networks ensembled: They have different architectures (including CBRe, P, D, etc. layers) and receive 12 single-lead and one 12-lead signals.; Beat-based; Averaged metrics for each class
(26)	I-{CoB}//12-Lx2-ASo-O	{CoB}: I-CCPCCPCCCPCCCPCCCP-O; Beat-based
(45)	I-{{FE}//{CBRe{CBReCBRe}x16{P//P}}}-DSo-O	{FE}: Morphological feature (QRS, RR, etc.) extraction
(27)	I-Gb//8ReDSo-O	Beat-based; Downsized to 8 from 12 leads
(36)	I-{{CRe}x3Dr}x5-LbReDrABReDrD-O	
(73)	I-CBReP{Res}x4PDSi-O	{Res}: I-{{CBReDrCB}//{}}Re-O
(32)	I-{C{As}{At}}x5-GbPSo-O	{As}: I-{P//P}DD{P//P}Si-O; {At}: I-{P//P}CSi-O; "Spatio-temporal" attention mechanisms
(62)	WT - PFA - Bagged Tree	Tensorization with WT (3rd order) to produce 36 features
(46)	I-CBReP{{CoB}P{IDEN}}x4PF{DReDr}x2Si-O	{CoB}: I-{{CBReCBRe}//{CB}}Re-O; {IDEN}: I-{{CBRe}//{}}Re-O; Outperforms human experts

[†], I, input; O, output; C, convolutional layer; F, flatten layer; G, gated recurrent unit (GRU) layer; Gb, bidirectional GRU layer; L, long-short term memory (LSTM) layer; Lb, bidirectional LSTM layer; B, batch normalization layer; A, attention layer; Re, ReLu activation layer; P, pooling layer; D, dense (fully connected) layer; Dr, dropout layer; So, Softmax activation; Si, Sigmoid activation; x, number of layer/module consecutive repetitions, e.g., Cx3 means 3 convolutional layers one after the other; {}, wraps a module/block; //, in parallel (if accompanied by a number, e.g., //3, it indicates the number of same modules running in parallel); QRS, QRS complex (ECG feature); HMM, Hidden Markov model; kNN, k-nearest neighbor; SVM, support vector machine; GBM, Gradient Boosting Machine; FT, fourier transformation variant; WT, wavelet transformation variant; n.a., not available. [‡], MI, myocardial infarction; PCA, principal component analysis; NN, neural network; CNN, convolutional NN; RNN, recurrent NN; RR, RR interval (ECG feature); Sw, Swish activation (x*Si(x)); sec, seconds; EF, ejection fraction; LVSD, left ventricle systolic dysfunction; echo, echocardiogram; proBNP, pro B-type natriuretic peptide (heart failure biomarker); AUC, area under the curve; AF, atrial fibrillation; SR, sinus rhythm; CSE, Common Standards for Electrocardiography database; PCinC2020, Physionet/Computing in Cardiology challenge 2020; ACC, accuracy.

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Table S2 Clinical conditions used as classification labels across studies

Abbreviation	Clinical condition	Frequency
MI	Myocardial infarction	21
AMI	Anterior MI	10
IMI	Inferior MI	10
ALMI	Anterolateral MI	8
ILMI	Inferolateral MI	8
ASMI	Anteroseptal MI	7
IPLMI	Inferoposterolateral MI	4
PMI	Posterior MI	2
IPMI	Inferoposterior MI	2
PLMI	Posterolateral MI	2
oMI	old MI	1
EMI	Early progression of MI	1
AcMI	Acute MI	1
CMI	Chronic MI	1
AF	Atrial fibrillation	16
I-AVB	1st degree atrioventricular block	12
RBBB	Right BBB	12
PAC	Premature atrial contraction	11
PVC	Premature ventricular contraction	11
LBBB	Left BBB	7
Tc	T-wave change	6
STD	ST-segment depression	5
STE	ST-segment elevation	5
LAFB	Left anterior fascicular block	4
ER	Early repolarization	4
LVSD	Left ventricular systolic dysfunction	2
II-AVB	2nd degree atrioventricular block	2
BBB	Bundle branch block	2
ST	Sinus tachycardia	2
LVHV	Left ventricle high voltage	2
STc	ST-segment change	2
HMD	Heart muscle defect	2
LVH	Left ventricular hypertrophy	2
VT	Ventricular tachycardia	2
SRa	Sinus-rhythm arrhythmia	1
Lad	Left axis deviation	1
WPW	Wolf-Parkinson-White syndrome	1
Afl	Atrial flutter	1
hyperK	Hyperkalemia	1
VpES	Ventricular pre-excitation syndrome	1
SVT	Supraventricular tachycardia	1
LAtH	Left atrial hypertrophy	1
–	Hypertrophy	1
CAD	Coronary artery disease	1
PAH	Pulmonary arterial hypertension	1
HyC	Hypertrophic cardiomyopathy	1
CA	Cardiac amyloidosis	1
MVP	Mitral valve prolapse	1
–	asystole	1

Frequencies pertain to the number of appearances of each clinical condition in the included studies. These clinical terms are stated as reported in each study. The MI superclass includes all the specific MI subcategories (indented).

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Table S3 Detailed performance metrics reported in each study

Study	AUPRC	AUC	ACC	F1	SEN	SPE	PPV	NPV
(64)		0.89	0.86		0.74	0.87	0.4	0.97
(21)		0.93	0.86		0.86	0.86		
(22)		0.87	0.79	0.39	0.79	0.8		
(58)			0.99	0.99	0.99	0.99		
(30)		0.91	0.97	0.84				
(29)			0.98	0.96	0.98	0.98	0.96	
(54)			0.74	0.76	0.75	0.74		
(31)			0.63		0.64	0.63		
(49)			0.93					
(40)			1		1	1		
(47)				0.87				
(41)		1	0.99		1	0.99	0.91	1
(28)			0.75		0.87	0.92		
(48)			0.93	0.9	0.9	0.98	0.9	
(50)			0.82		0.79	0.88		
(33)			0.93		0.94	0.86	0.97	
(34)			0.88		0.86	0.88		
(65)		0.88	0.81	0.82	0.86	0.76	0.79	0.85
(63)				0.99	0.99		0.99	
(35)				0.74				
(59)			1		1	1		
(37)			0.72					
(51)			0.98					
(23)			0.98		0.98	0.99		
(24)	0.21	0.83						
(38)				0.93	0.93	1	0.92	
(25)			0.57					
(42)					0.93	0.9	0.94	
(55)		0.87						
(52)			0.86					
(53)			0.98					
(56)			1					
(57)			1		1	1		
(43)				0.86				
(44)		0.95			0.96	0.95		
(26)			0.85	0.81	0.8		0.83	
(45)				0.88				
(27)			1					
(36)			0.95					
(73)		0.97	0.97	0.81	0.81		0.82	
(32)			0.87	0.84				
(62)			0.99		1	1		
(46)		0.98		0.89	0.87	1		

AUPRC, area under the precision-recall curve; AUC, area under the curve; ACC, accuracy; F1, F1-score; SEN, sensitivity; SPE, specificity; PPV, positive predictive value; NPV, negative predictive value.

References

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