November 13–14, 2024 | Online

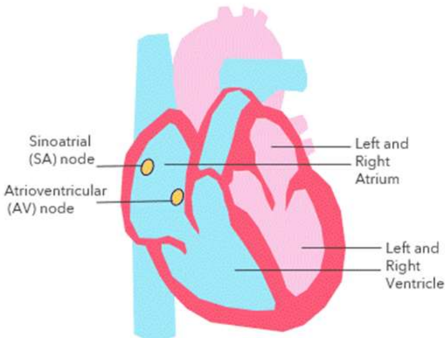
Atrial Fibrillation Detection with Ensemble of Features Based CNN for Insertable Cardiac Monitors

Shantanu Sarkar PhD
Medtronic Inc.

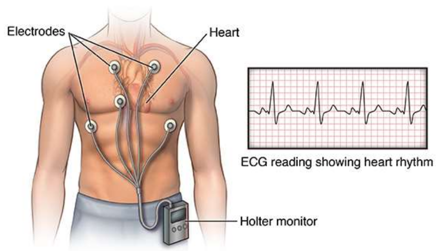
MATLAB EXPO

Electrocardiography (ECG)

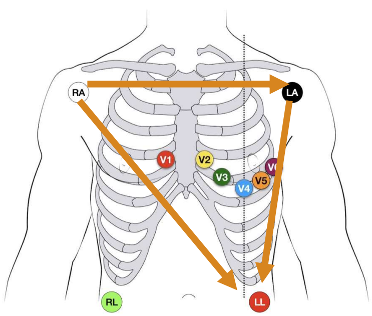
Monitoring and Diagnosis options



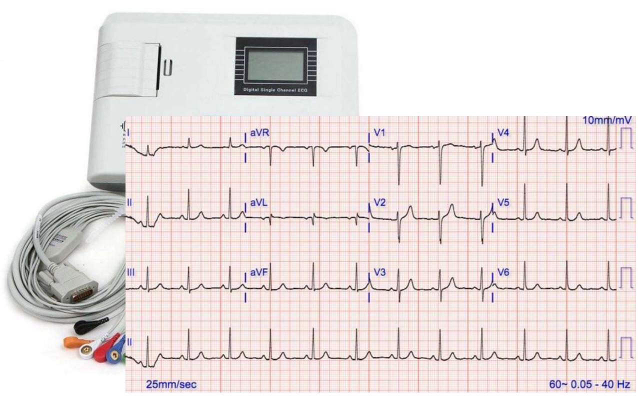
Holter Monitoring



Wearables / External Monitoring systems

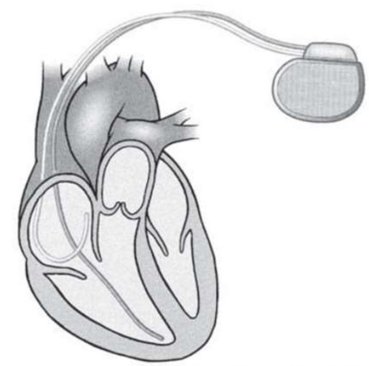


In Office ECG



Implantable Monitors

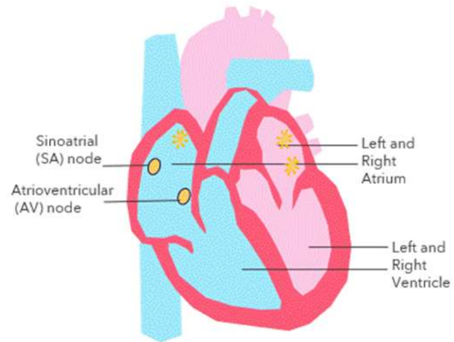
Implantable Therapy devices

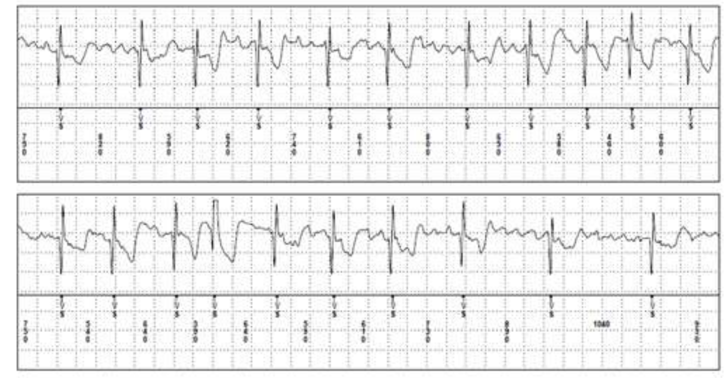


Why Atrial Fibrillation matters

Stroke, Heart Failure, Symptoms

- Atrial fibrillation (AF) can lead to
  - Stroke
  - Progression to Heart Failure (HF)
  - Debilitating symptoms





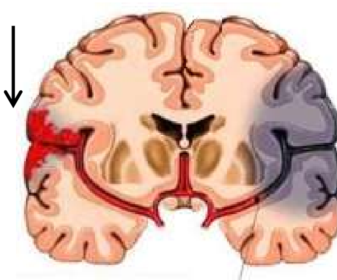
- **AF if often intermittent and asymptomatic**

- Cryptogenic Stroke
- 25% of ischemic strokes are cryptogenic
- May have underlying undiagnosed AF
- Detection of AF changes treatment
  - antiplatelets to oral anticoagulation

Stroke etiologies

Vessel Rupture (15%)

Artery Occlusion (85%)



•Cryptogenic (25-40%)
Unknown cause

Adams HP Jr, *Stroke*. Jan 1993; 24; 35-41;
Camm et al, *European Heart Journal* . 2012; 33, 2719-2747

AF – The Clinical Questions

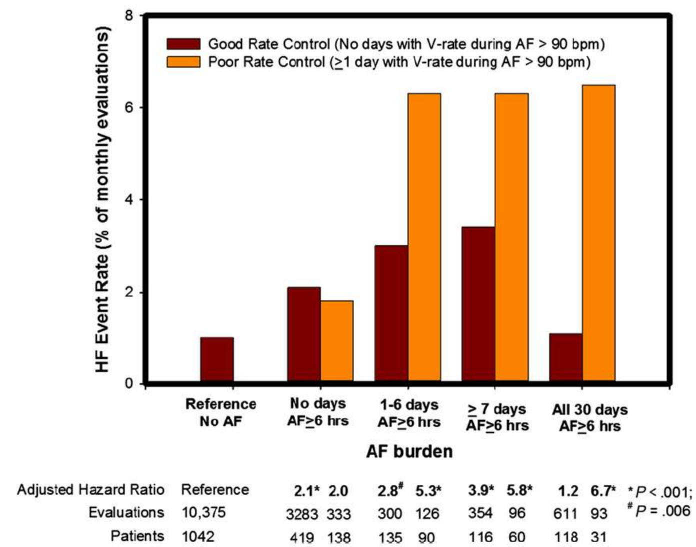
Clinical Diagnostic Questions

1. Does patient have AF ?
2. How much AF does patient have ?
3. What is the temporal characteristics of AF?
4. What is the ventricular rate during AF?
5. Does patient have clinical risk factors ?

Treatments

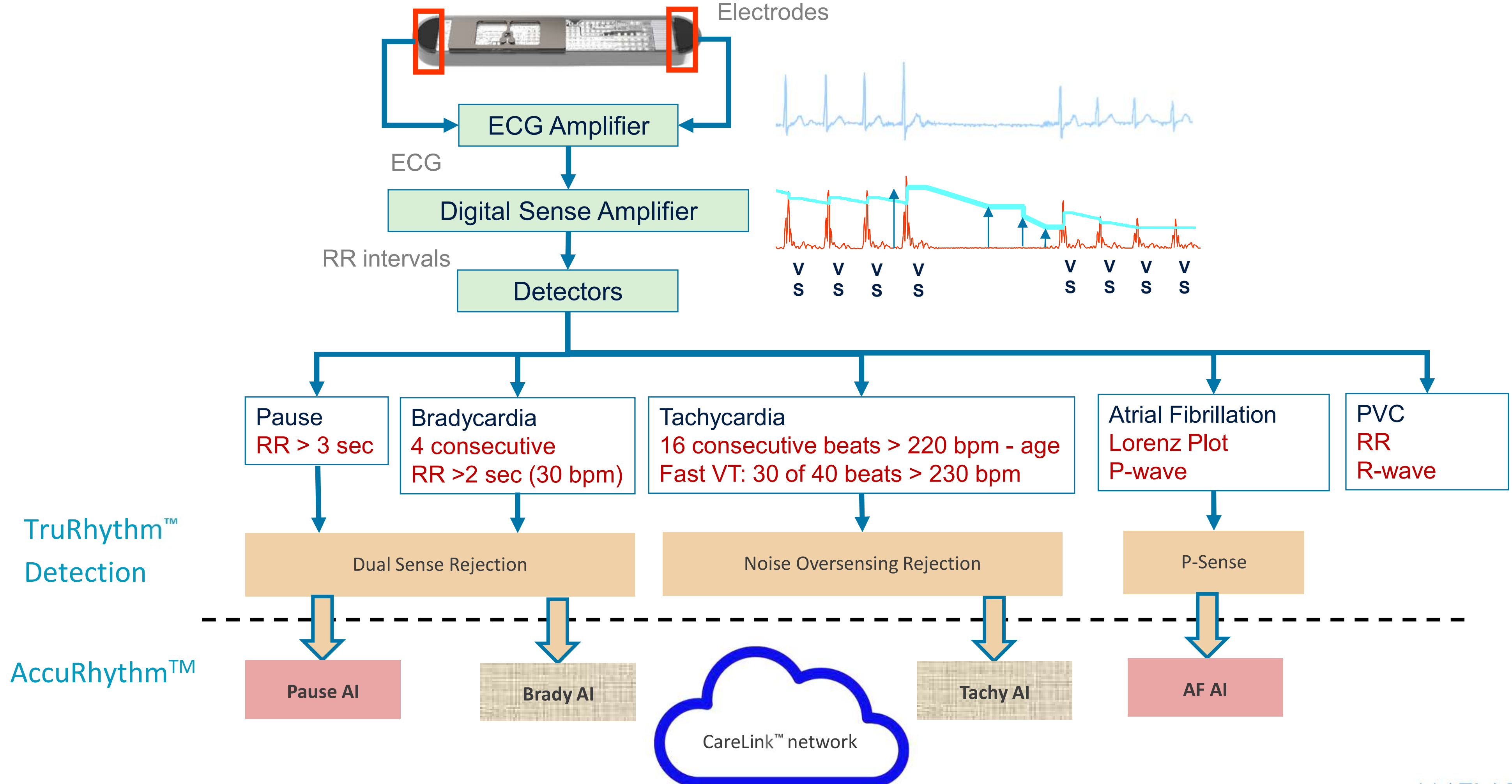
1. Anticoagulation management
2. Rhythm Control
   a) AF ablation
   b) Antiarrhythmic drugs
3. Rate Control
   a) AV node ablation and pacing
   b) Beta Blockers, Digoxin, etc.

Maximum Daily AF Duration	CHA$_2$DS$_2$-VASc Score: 0 n=2922 (13.4%)	1 n=2151 (9.9%)	2 n=4554 (20.9%)	3-4 n=7164 (32.9%)	≥5 n=4977 (22.9%)
No AF n=16815 (77.2%)	0.33% 40 events	0.62% 46 events	0.70% 95 events	0.83% 139 events	1.79% 157 events
AF 6 min–23.5 h n=3381 (15.5%)	0.52% 11 events	0.32% 4 events	0.62% 17 events	1.28% 42 events	2.21% 36 events
AF >23.5h n=1572 (7.2%)	0.86% 4 events	0.50% 3 events	1.52% 19 events	1.77% 28 events	1.68% 13 events



Kaplan RM et al. Circulation. 2019 Nov 12;140(20):1639-1646.
Sarkar S et al. Am Heart J. 2012 Oct;164(4):616-24.

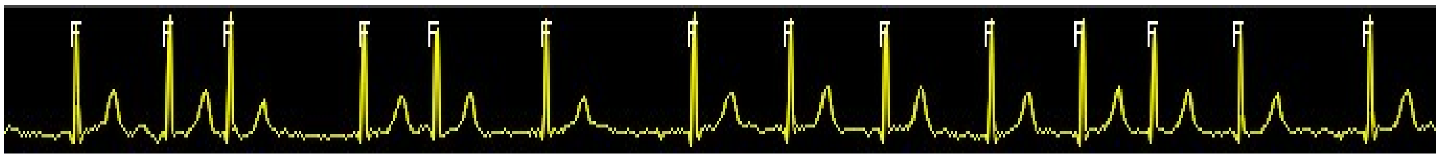
R-wave Sensing and Cardiac Arrhythmia Detection in ICMs



MATLAB EXPO

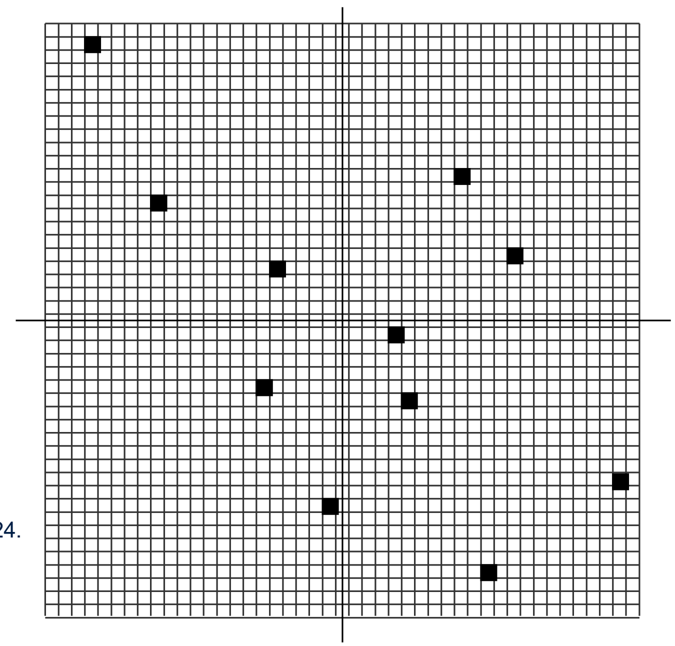
AF Detector Principle: Unpredictability of RR intervals

- Lorenz plot



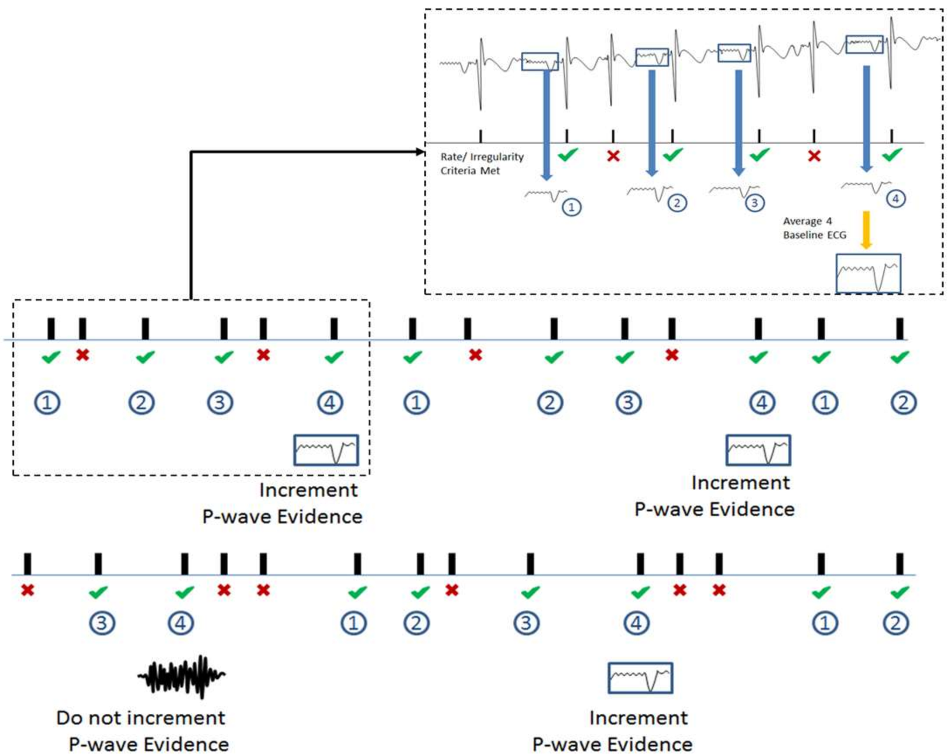
RR 670 435 960 520 800 1050 700 675 760 650 515 625 925

δRR -235 525 -440 280 250 -350 -25 85 -110 -135 110 300



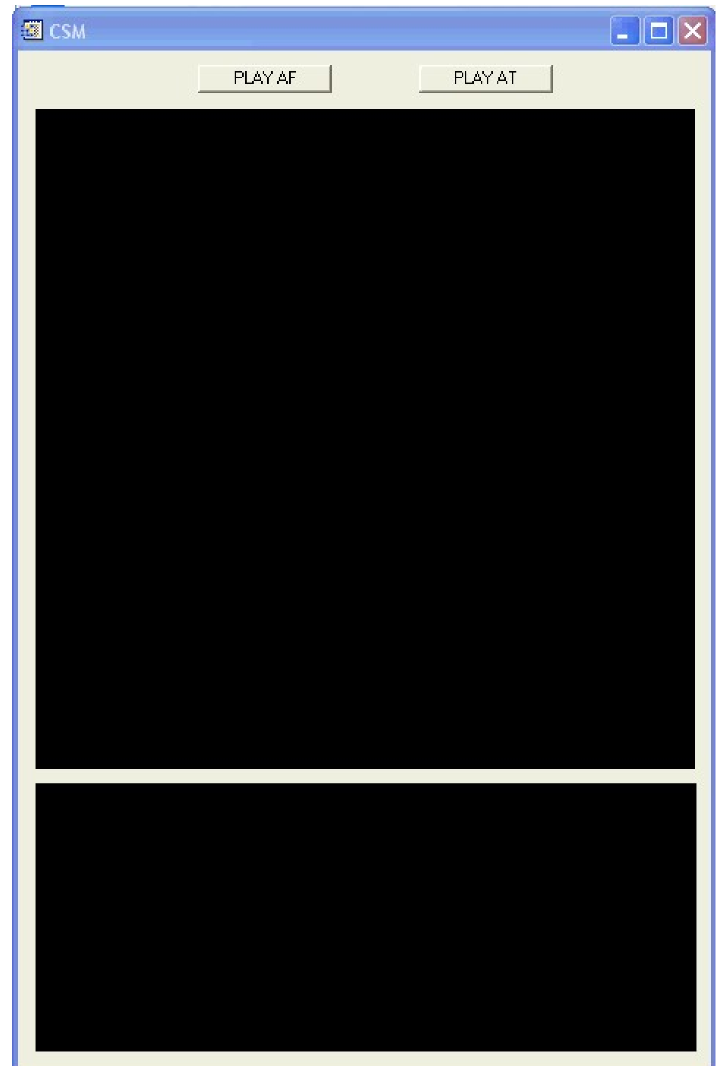
Sarkar S et al. *IEEE Trans Biomed Eng.*2008 Mar;55(3):1219-24.

AF detection in Insertable Cardiac Monitor



Lorenz Plot

AF Evidence



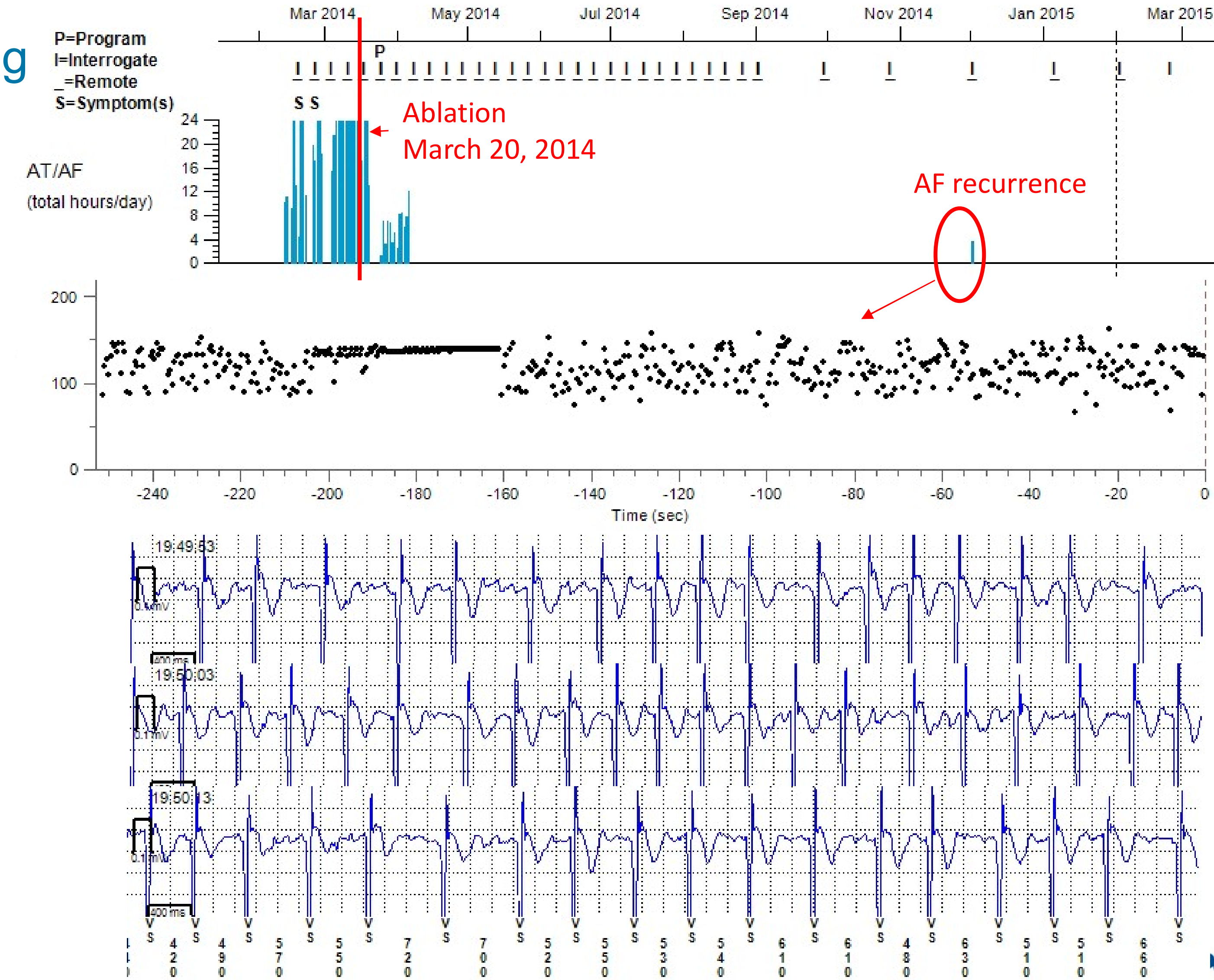
Sarkar S et al. IEEE Trans Biomed Eng. 2008 Mar;55(3):1219-24.
Pürerfellner H et al. Heart Rhythm. 2014; 11(9):1575-83.
Sanders P et al. Heart Rhythm. 2016; 13(7):1425-30.
H Pürerfellner, et al. EP Europace 20 (FI_3), f321-f328

Ambulatory AF monitoring

Duration Sensitivity	Duration Specificity
98.9%	99.8%

Episode* Sensitivity	Episode PPV*
97%	85%
	*Pts w/ Hx of AF

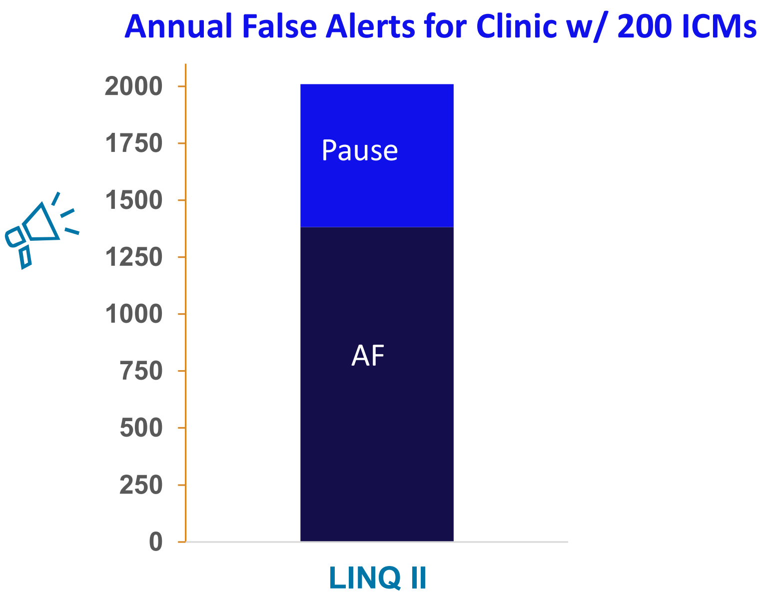
* >2min

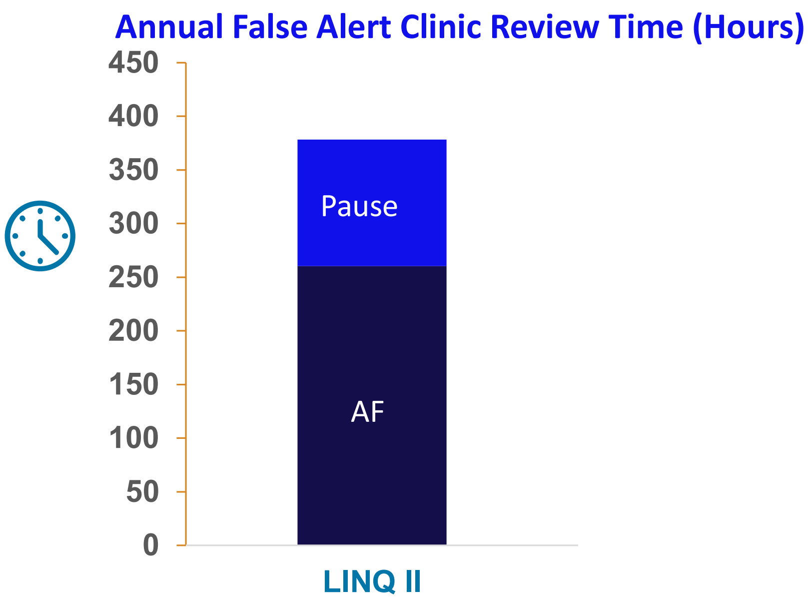


H Pürerfellner, et al. EP Europace 20 (FI_3), f321-f328

False Alerts and Episode Review Burden

Still an unmet clinical need

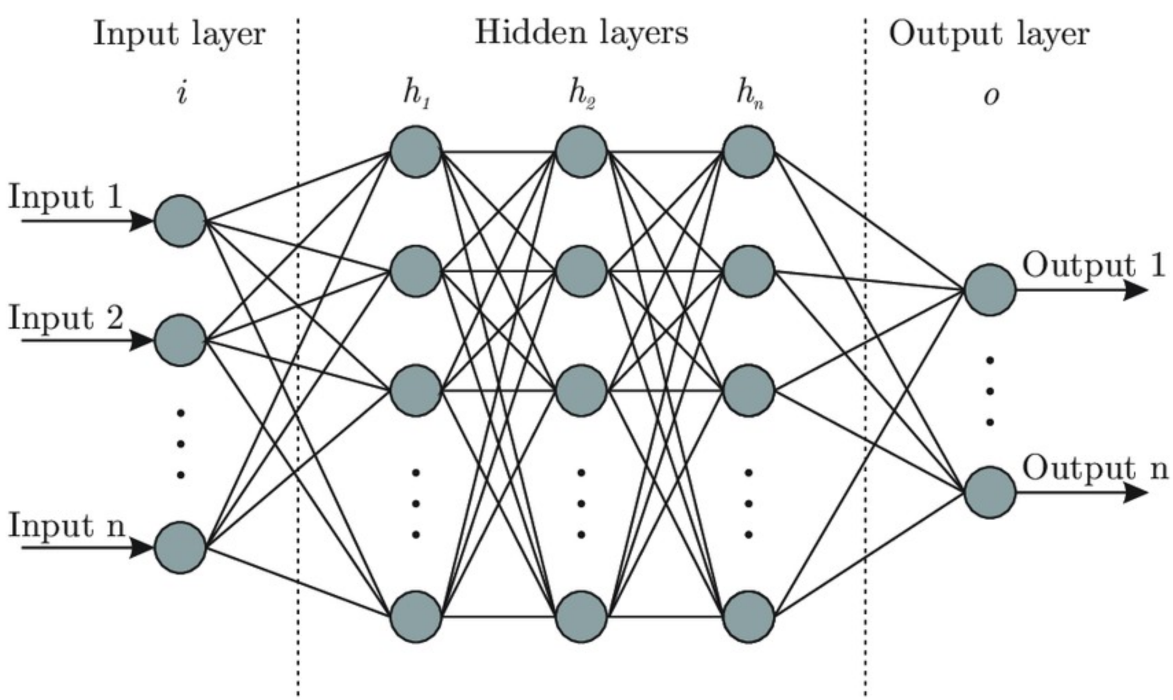




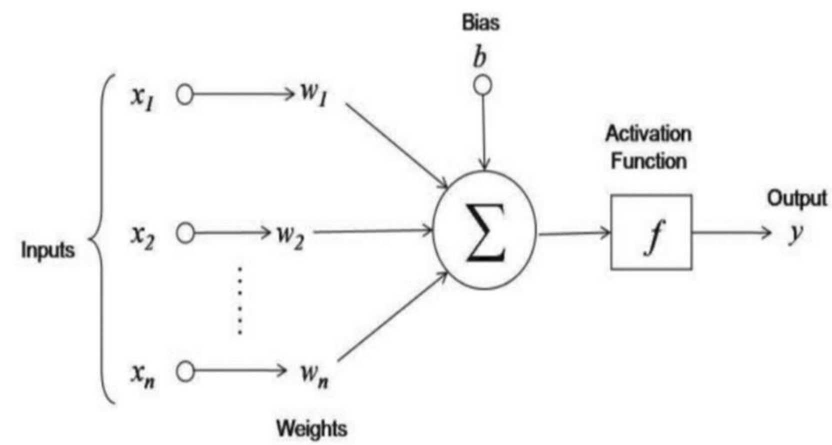
SOURCE: OUSDIGIAN, K. CHENG, YJ. KOEHLER, J. RADTKE, A. ROSEMAS, S. ROGERS, J. ARTIFICIAL INTELLIGENCE DRAMATICALLY REDUCES ANNUAL FALSE ALERTS FROM INSERTABLE CARDIAC MONITORS. AMERICAN HEART ASSOCIATION (AHA). PRESENTED AT AHA CONFERENCE. NOVEMBER 2021

Artificial neural network
CLASSIFICATION: FEATURES TO CLASSES

Network



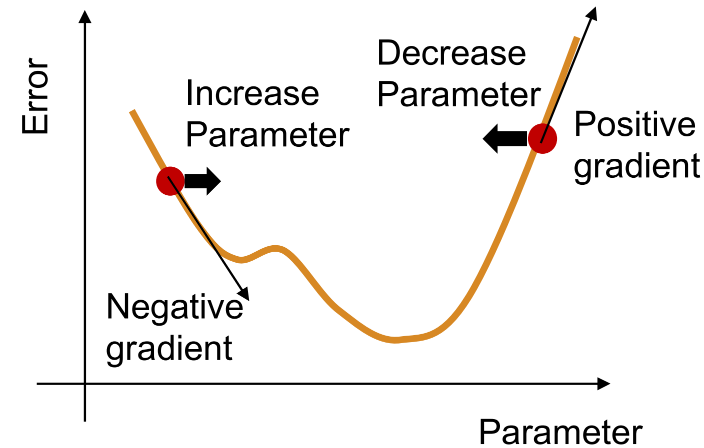
Each node of network

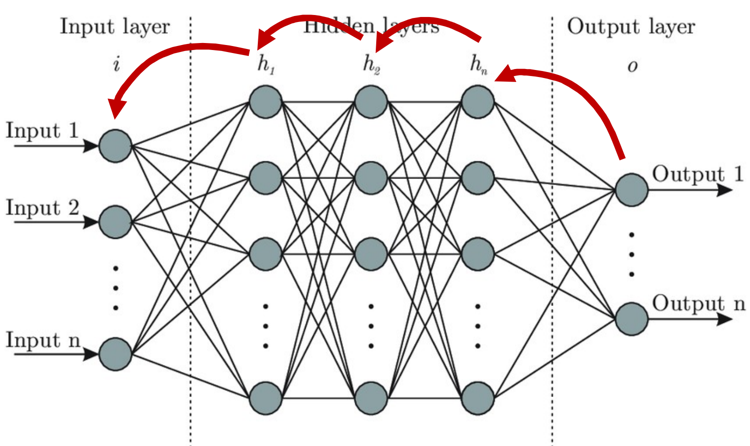


Training the network

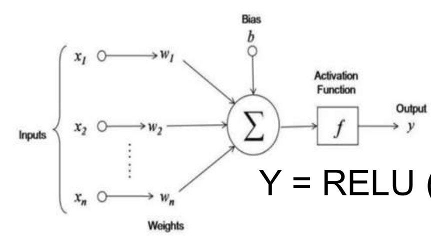
GRADIENT DESCENT, THE CHAIN RULE, AND BACKPROPAGATION

Updated Parameter = Current Parameter − Learning Rate × Gradient of Error wrt Parameter





h1 = RELU (dot(W1, i) + b1)
h2 = RELU (dot(W2, h1) + b2)
h3 = RELU (dot(W3, h2) + b3)
o = RELU (dot(W4, h3) + b4)



Y = RELU (dot(W, x) + b

f(W1, W2, W3, W4) = a(W4, b(W3, c(W2, d(W1))))

Chain rule: d/dx[f(g(x))] = f ’(g(x)) . g’(x)

DEEP LEARNING
CONVOLUTION NEURAL NETWORKS (CNN)

[CNN Explainer]

Raw Data → Feature Engineering → Classification

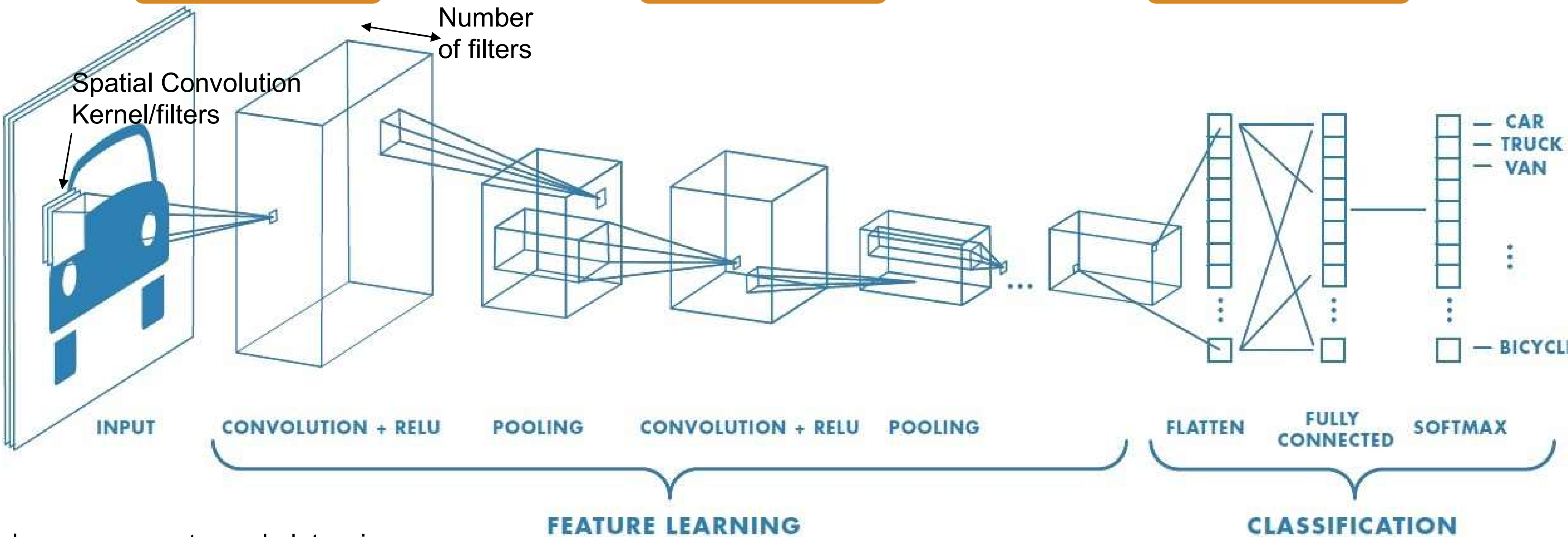
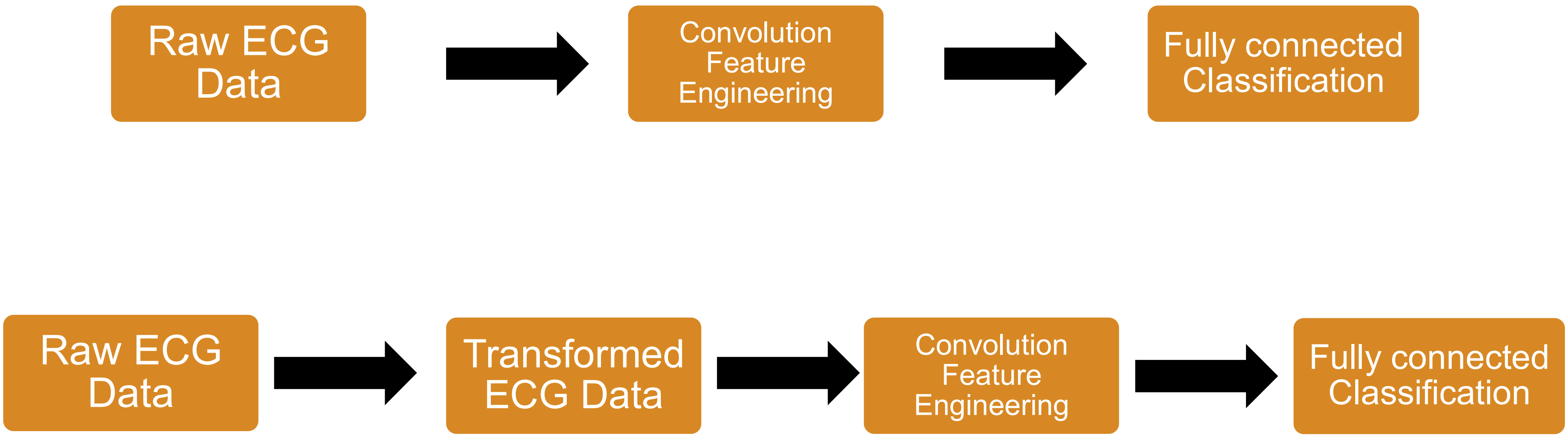


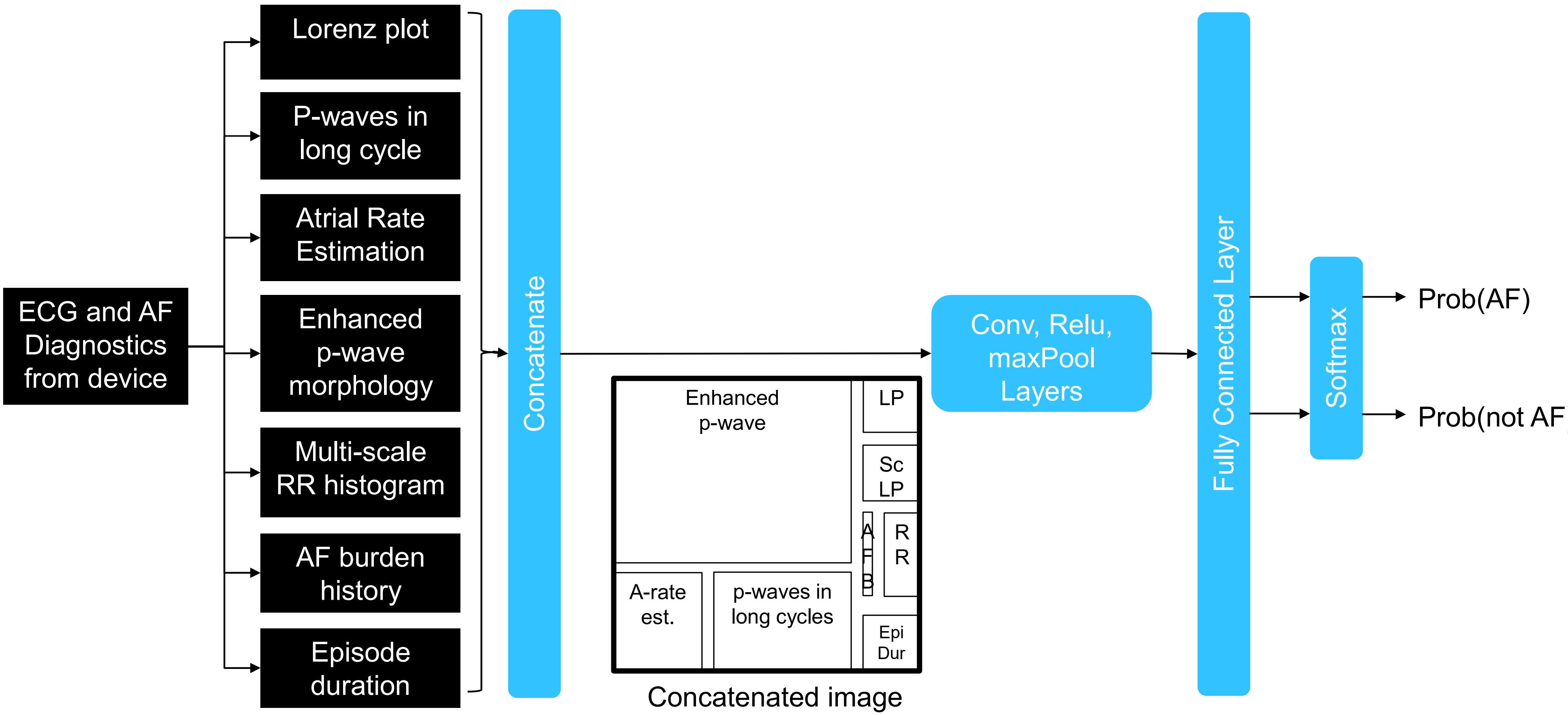
Image source: towardsdatascience.com

Artificial Intelligence for AF detection

VARIOUS POSSIBILITIES



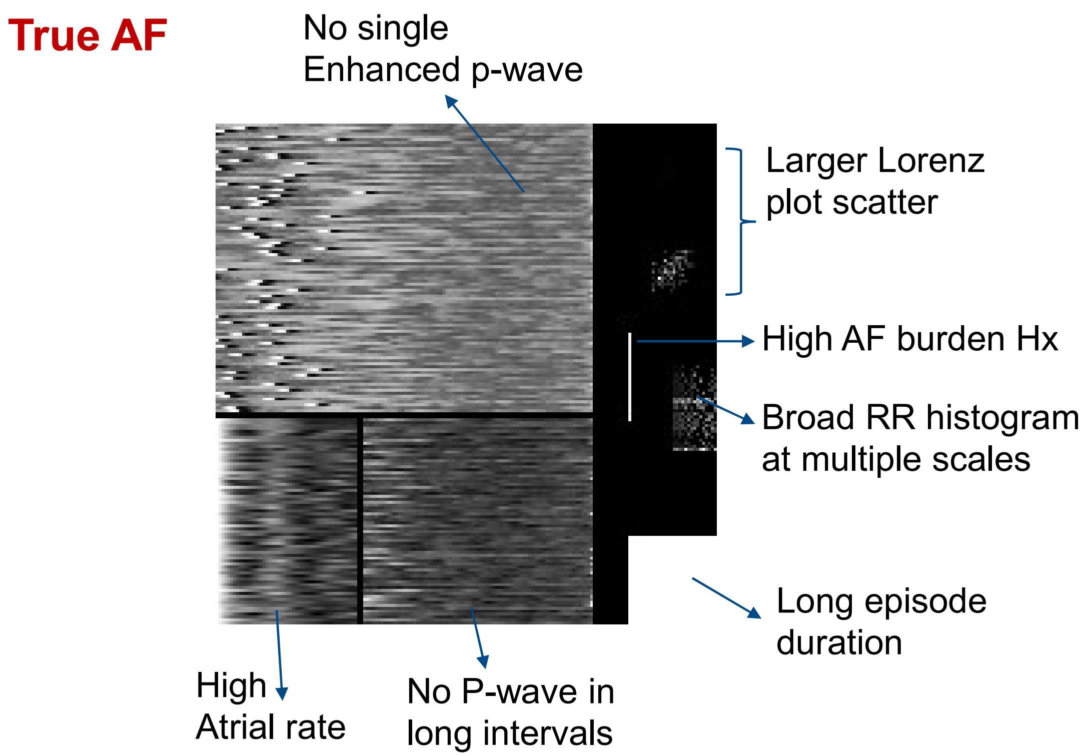
Convolution Neural Networks for AF Detection
USING ECG ELEMENTS USED FOR ANNOTATION

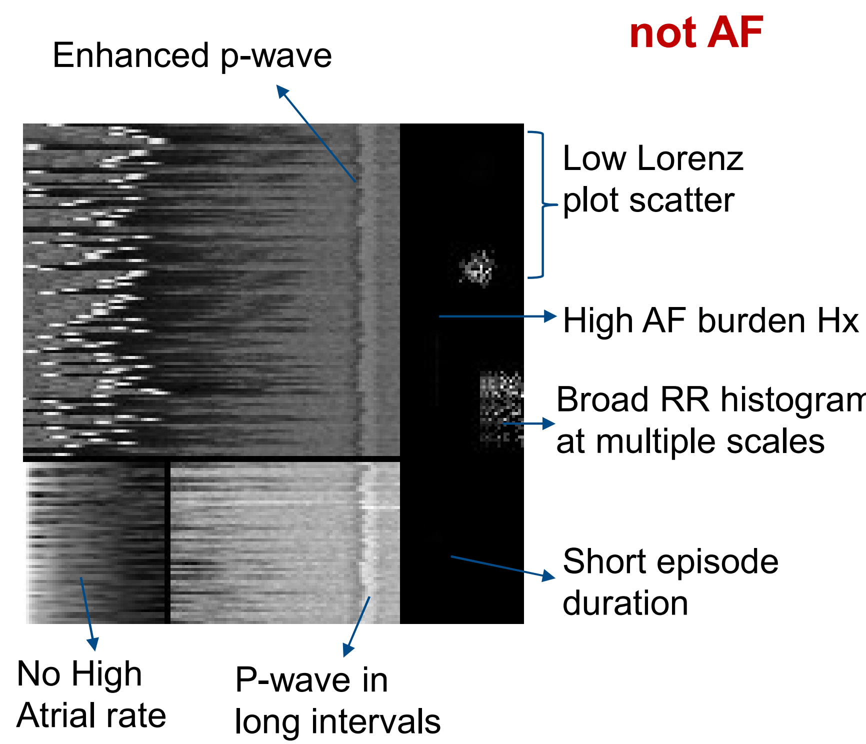


Sarkar S et al. Heart Rhythm O2. 2022 Nov 1;4(1):51-58.

ECG elements

TRANSFORMED ECG ELEMENTS - 2D IMAGE

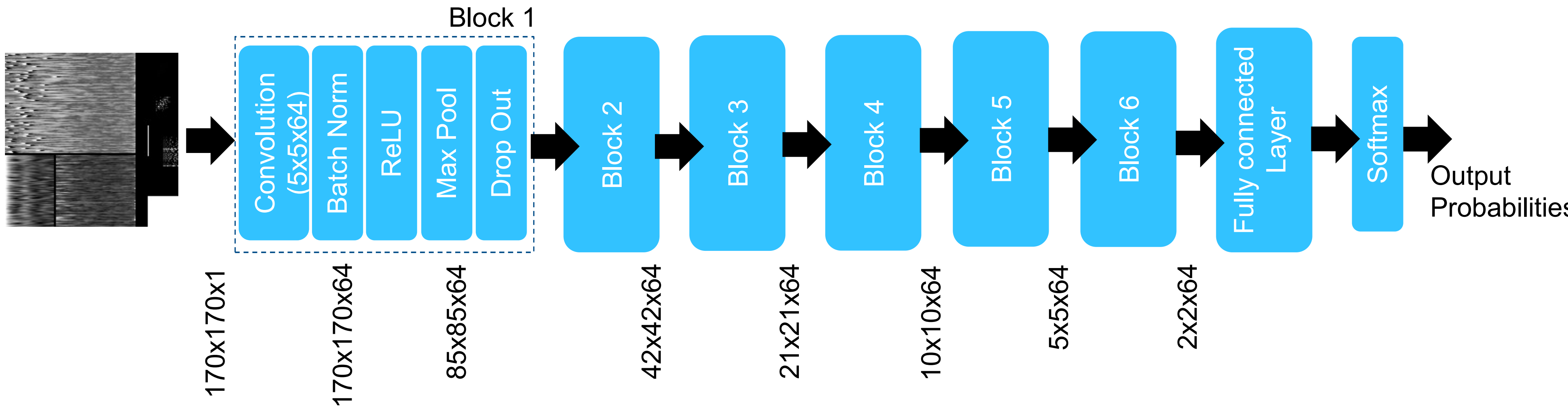




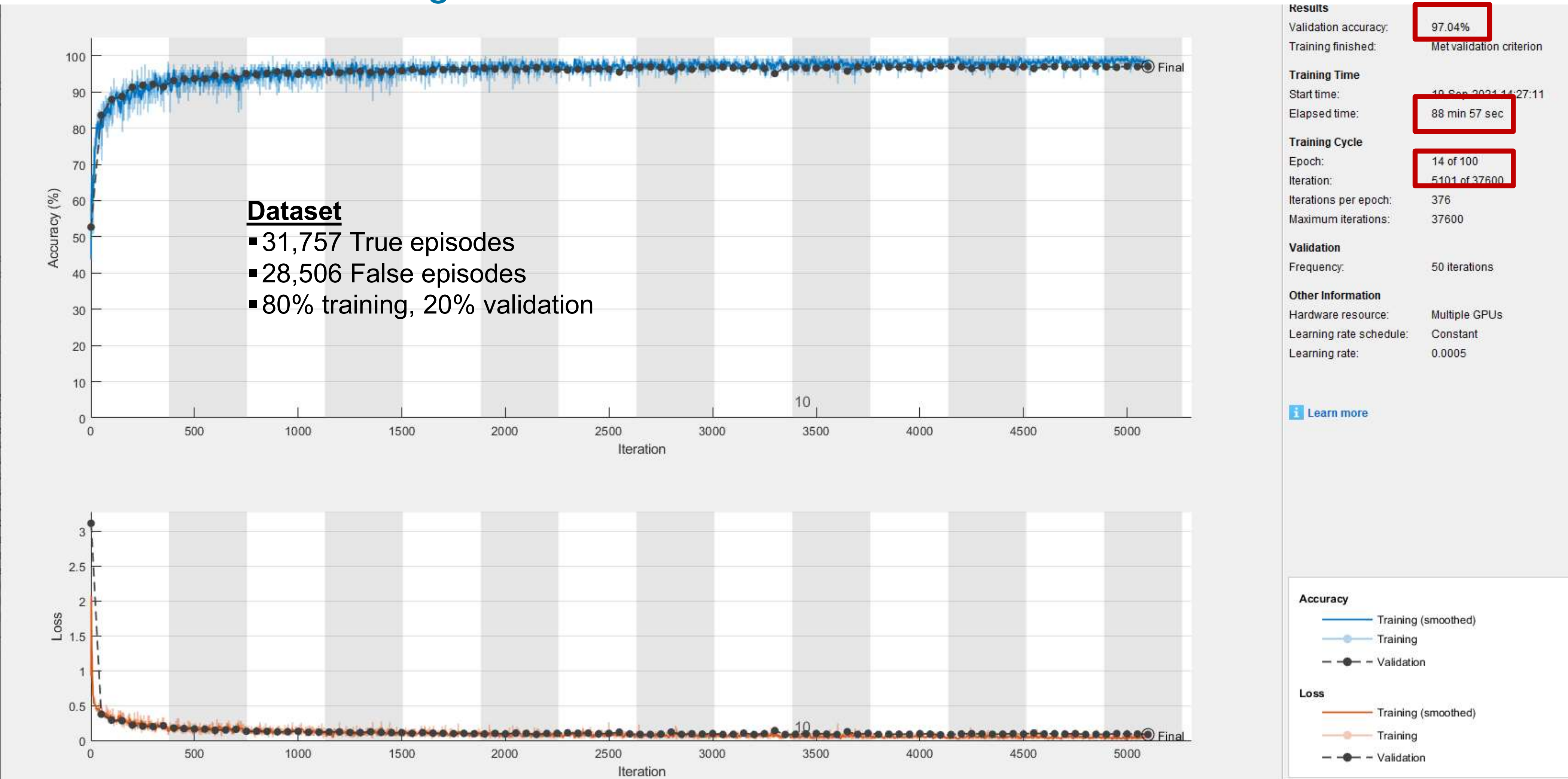
Sarkar S et al. Heart Rhythm O2. 2022 Nov 1;4(1):51-58.

CNN for AF detection

A CUSTOM NETWORK VS RESNET18

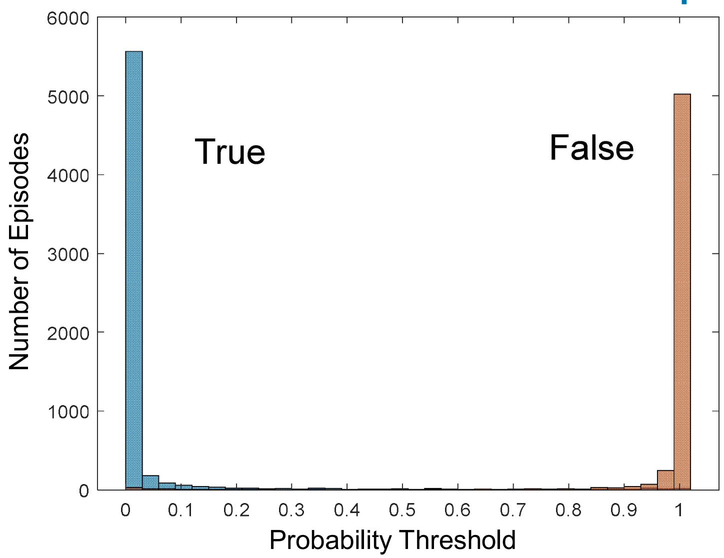


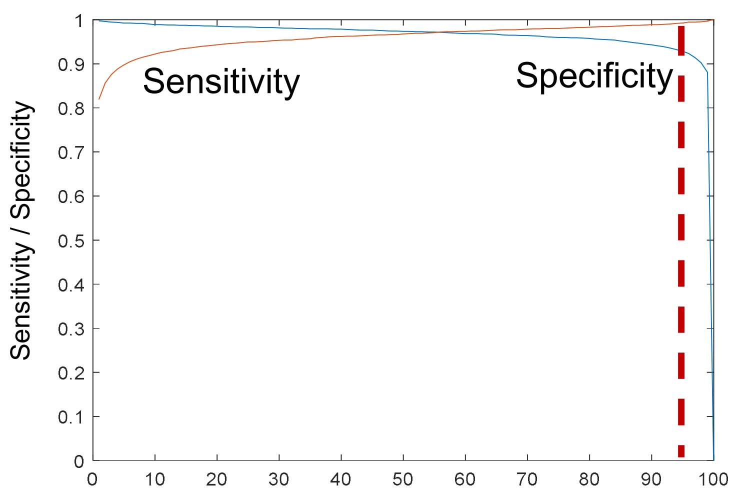
Custom CNN training

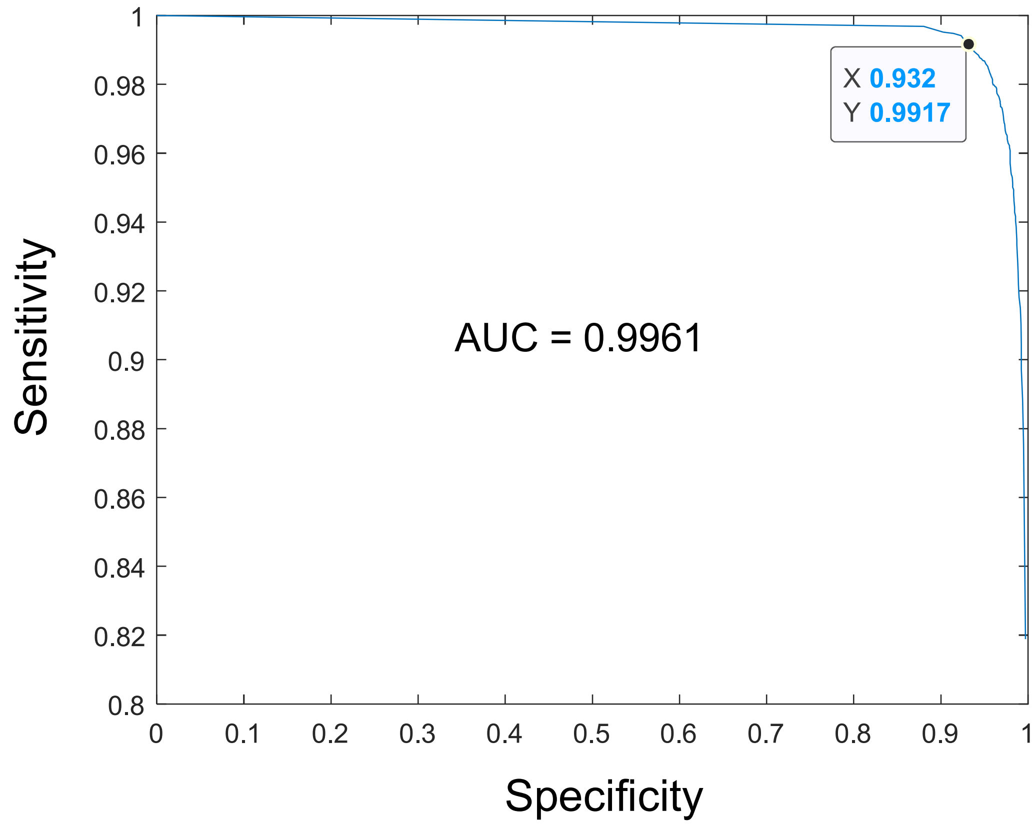


Dataset
- 31,757 True episodes
- 28,506 False episodes
- 80% training, 20% validation

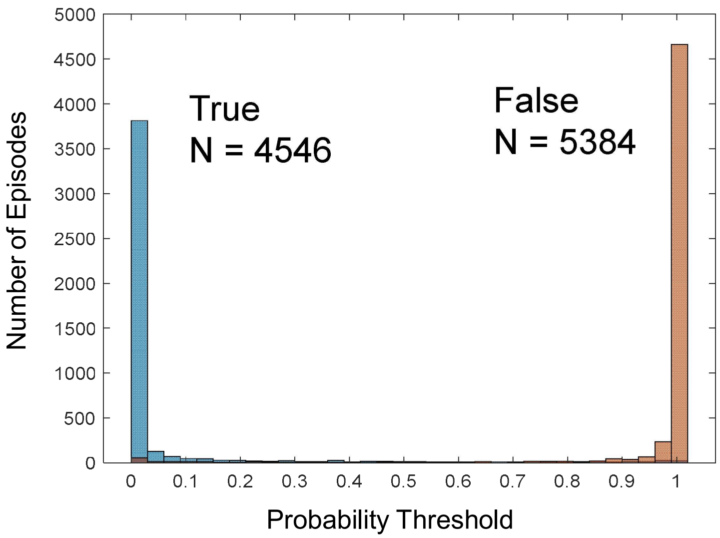
Custom CNN validation – Independent Episodes

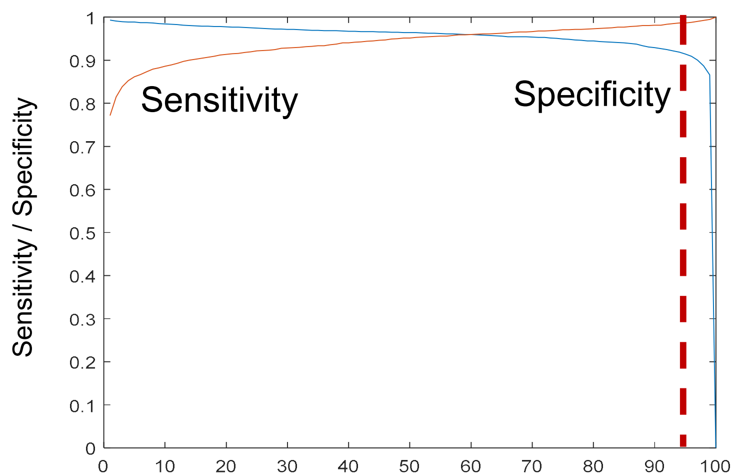


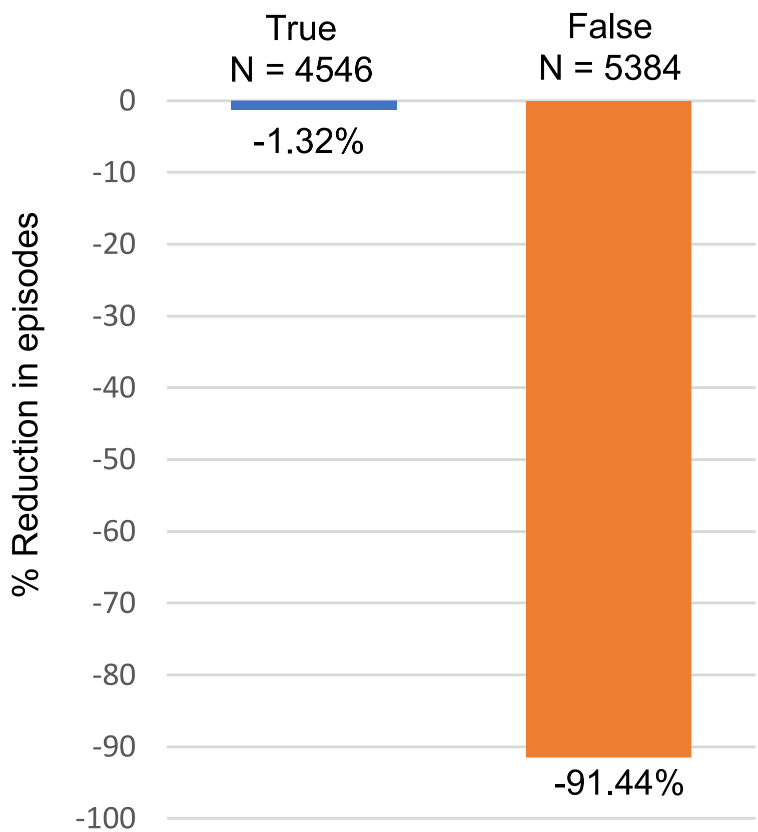




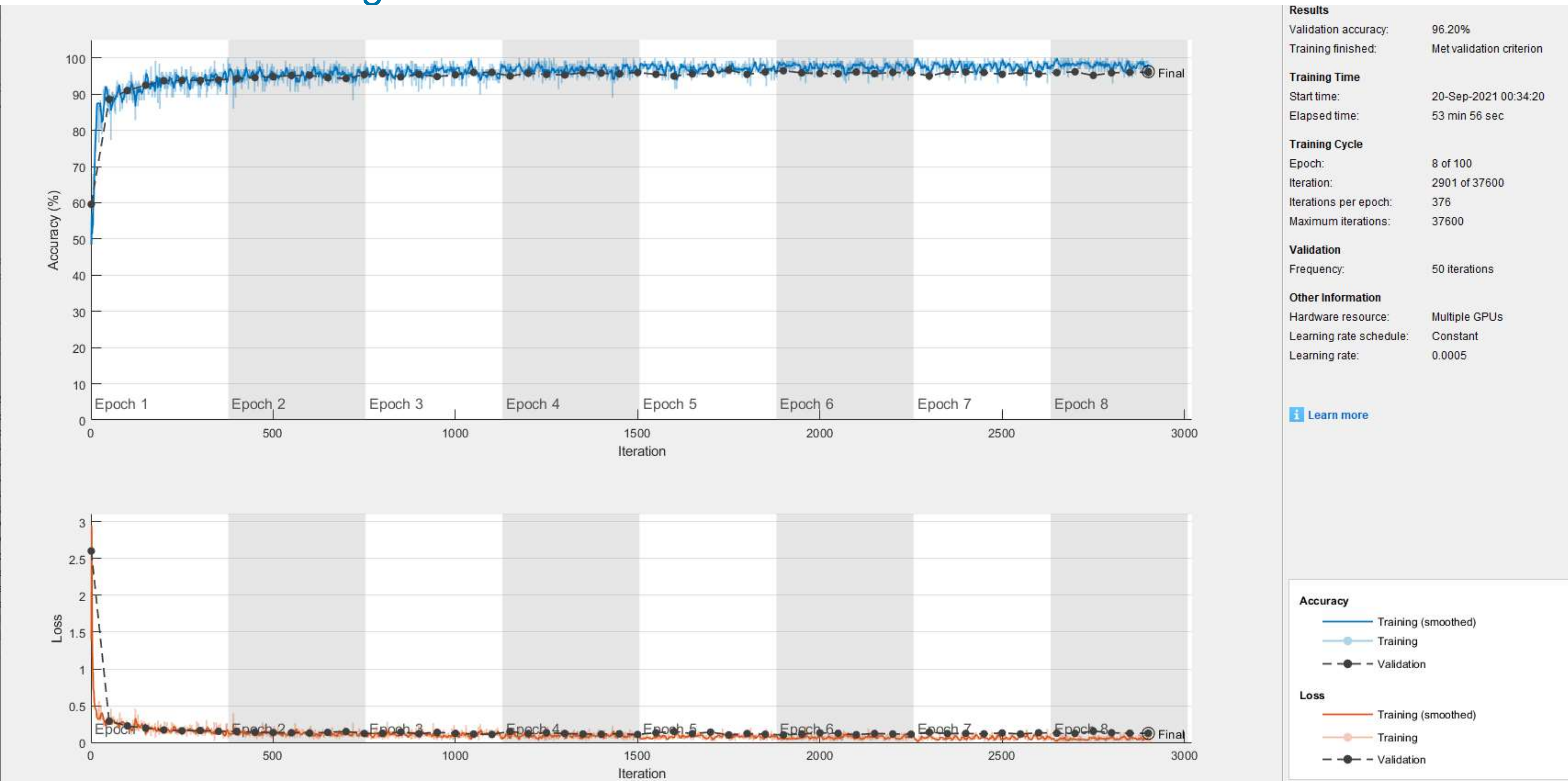
Custom CNN Test Set – Independent patients



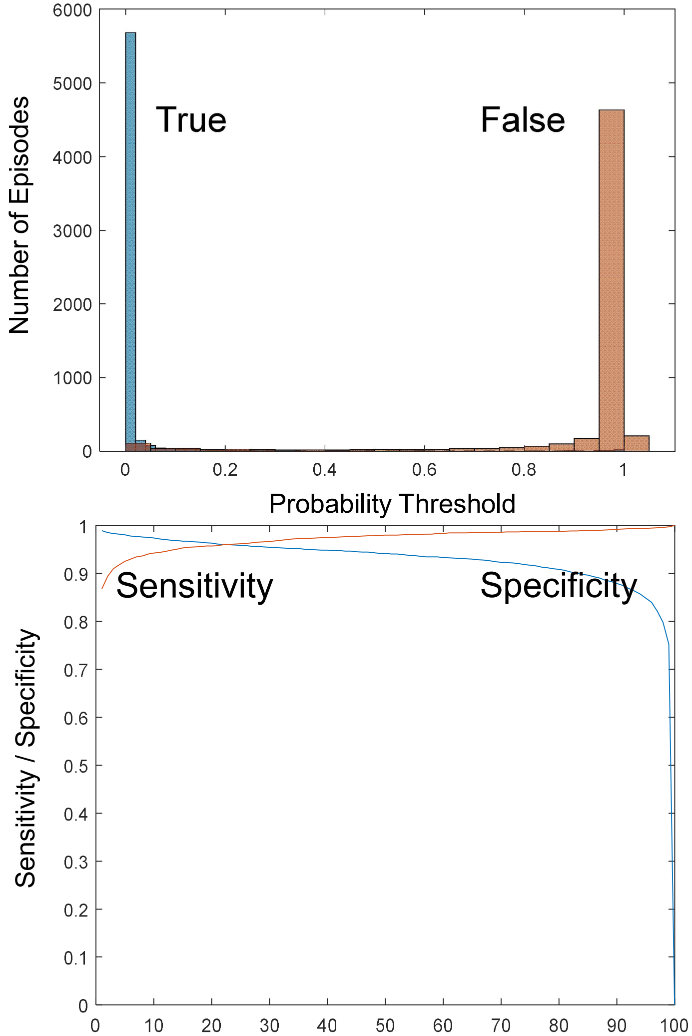


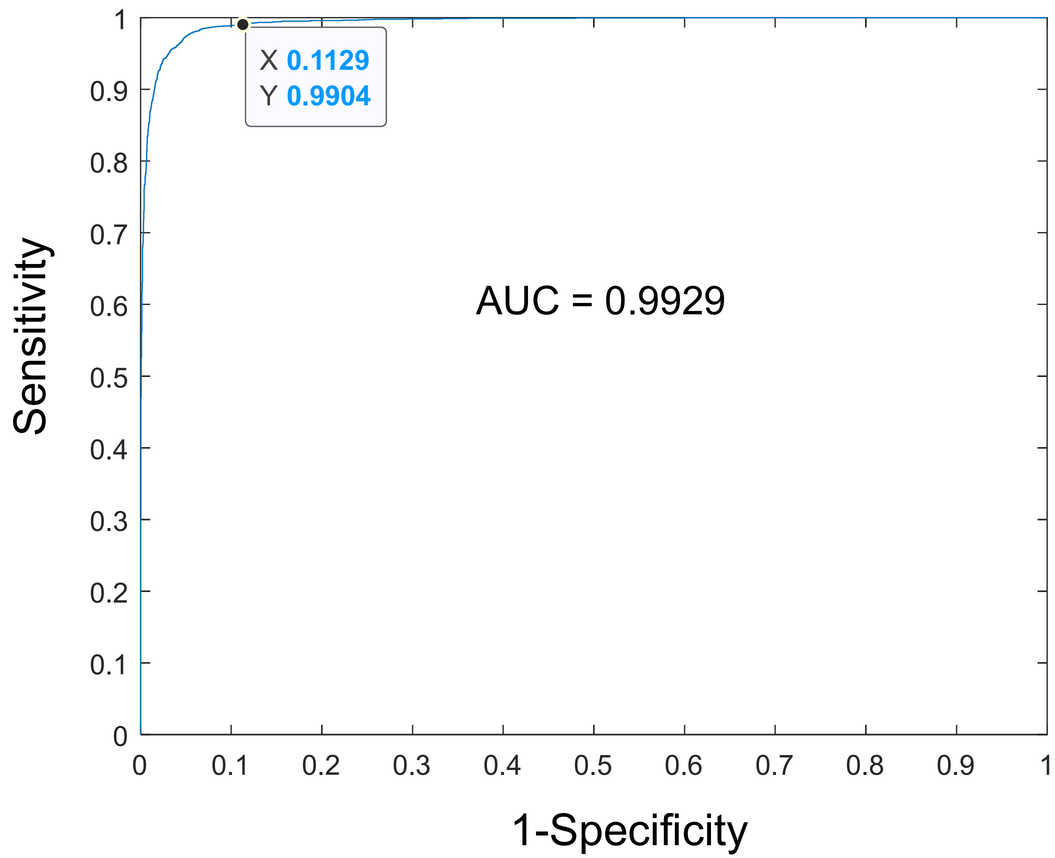


Resnet18 training

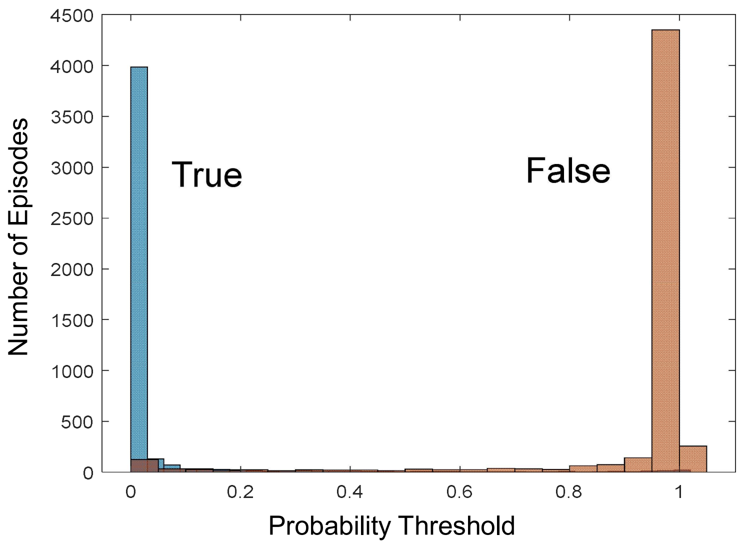


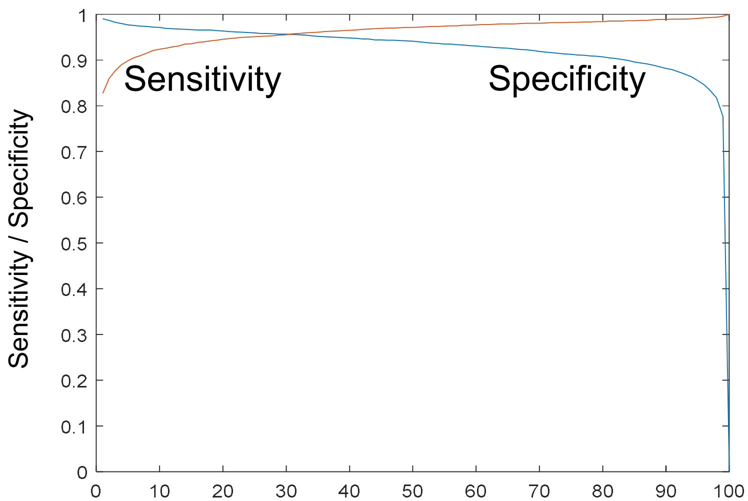
Resnet18 validation – Independent Episodes

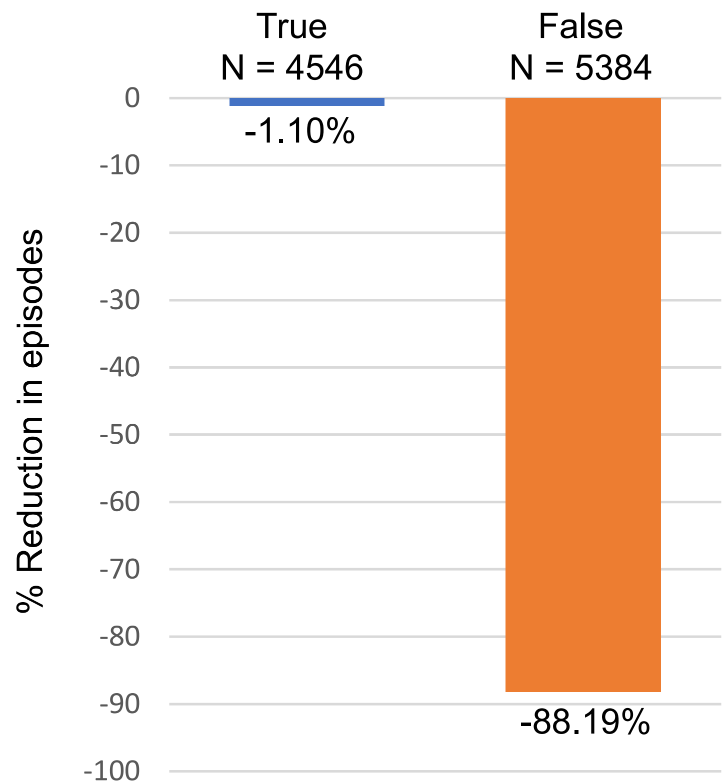




Resnet18 Test Set – Independent Patients

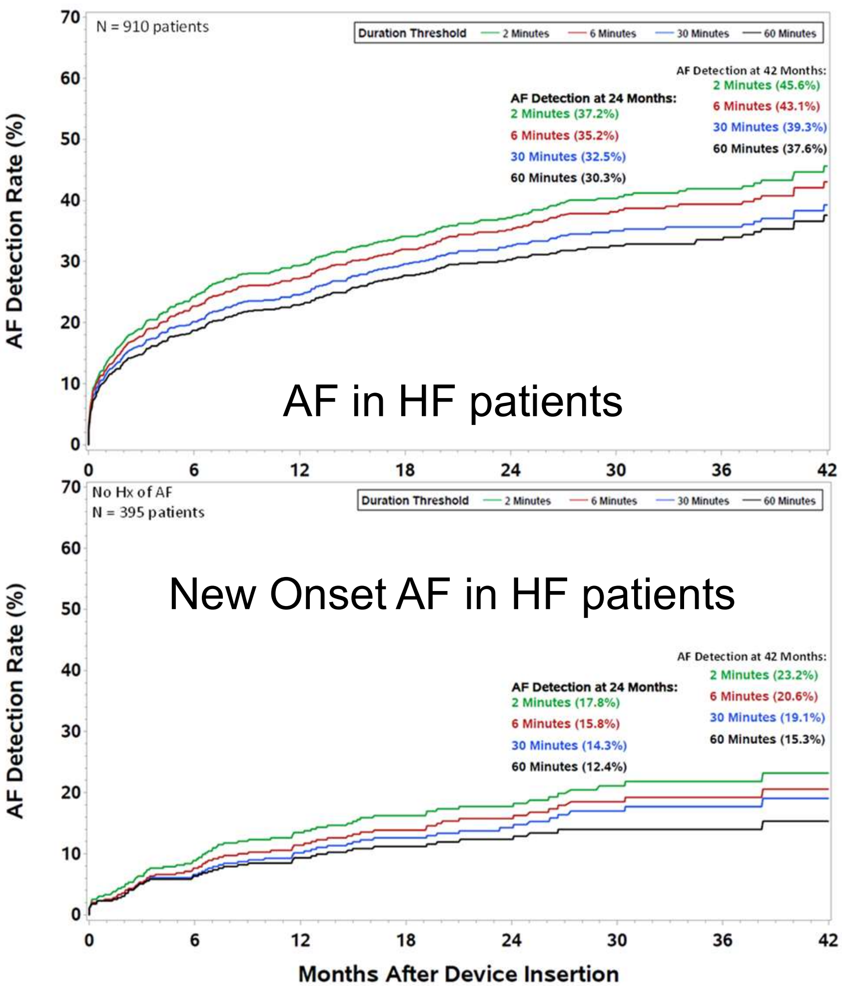






MATLAB EXPO

Applications of the AF detector using CNN on Ensemble of features

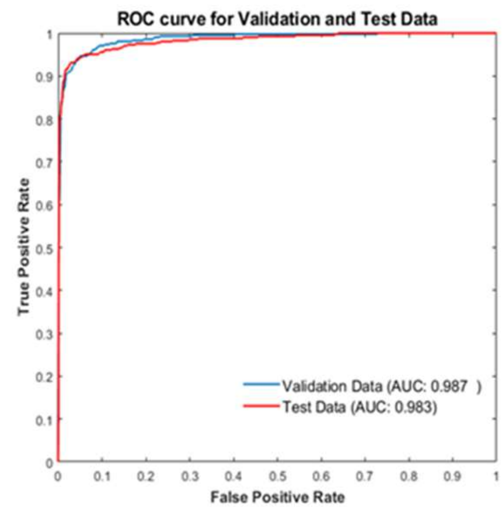


Shahzeb Khan M et al. Presented at ESC 2024.

Subclassifying Atrial Tachyarrhythmia

Validation Dataset Episodes		True AFL/AT YES	True AFL/AT NO	
Detected AFL/AT	YES	400	305	56.7%
	NO	13	2949	99.6%
		96.9%	90.6%	

Test Dataset Episodes		True AFL/AT YES	True AFL/AT NO	
Detected AFL/AT	YES	390	369	51.4%
	NO	16	2695	99.4%
		96.1%	88.0%	



Majumder S et al. Presented at ESC 2024.

AF Detection using CNN on Ensemble of features

SUMMARY

- ECG based AI has been shown to reduce false positive AF episodes while maintaining sensitivity
- Specific aspects of ECG, RR intervals and other information are useful in adjudicating AF episodes
- Features derived to encode information useful in adjudicating AF episodes were evaluated as potential input to a convolution neural network (CNN)
  - Lorenz plot; P-wave enhanced ECG Segments; Auto correlation of long intervals, RR interval histogram, AF burden history, episode duration
- Over 90% reduction in false positive AF detection could be obtained with around 1% reduction in false positives
- There is still a residual generalization error of < 2%

MATLAB EXPO

MathWorks®