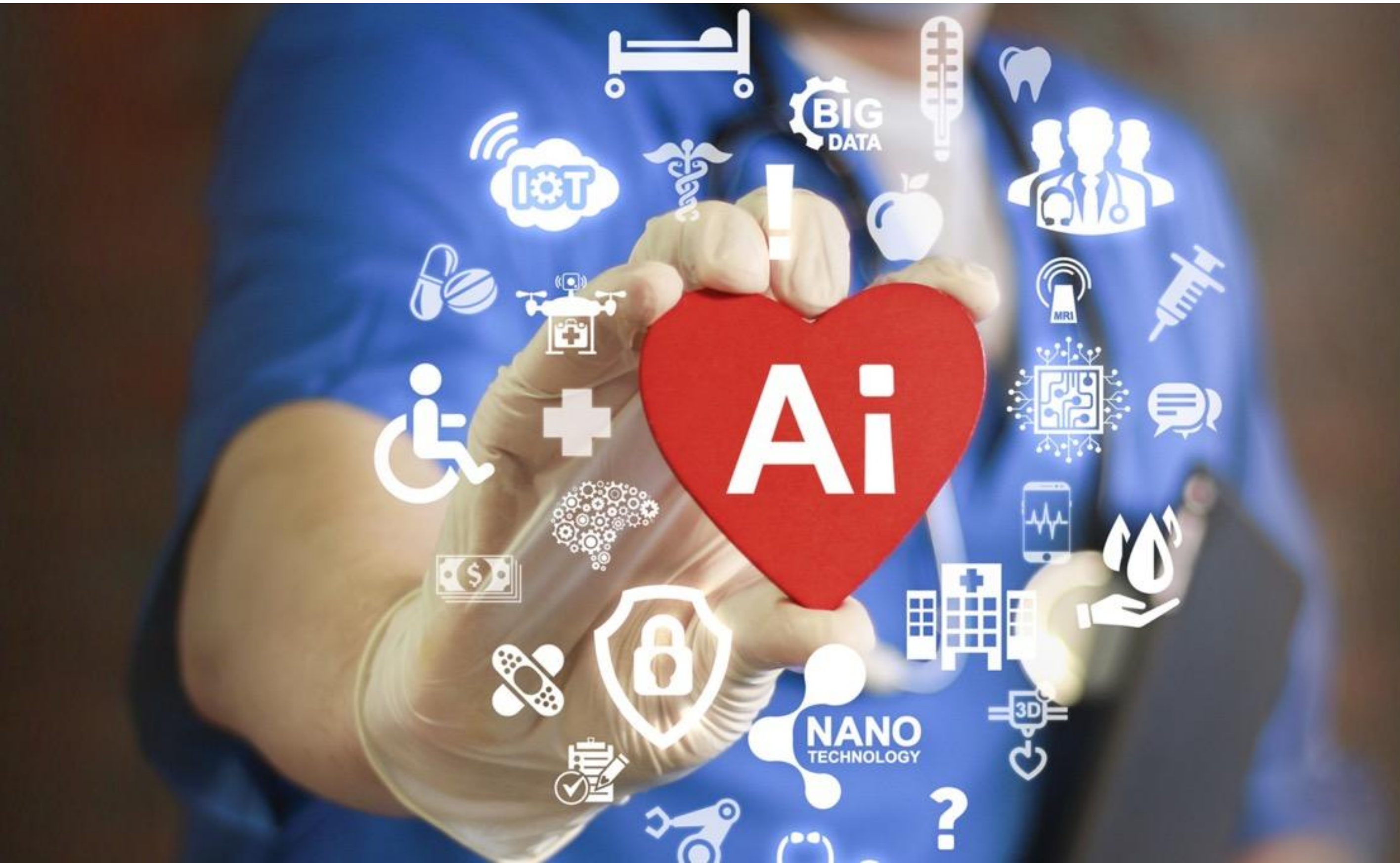
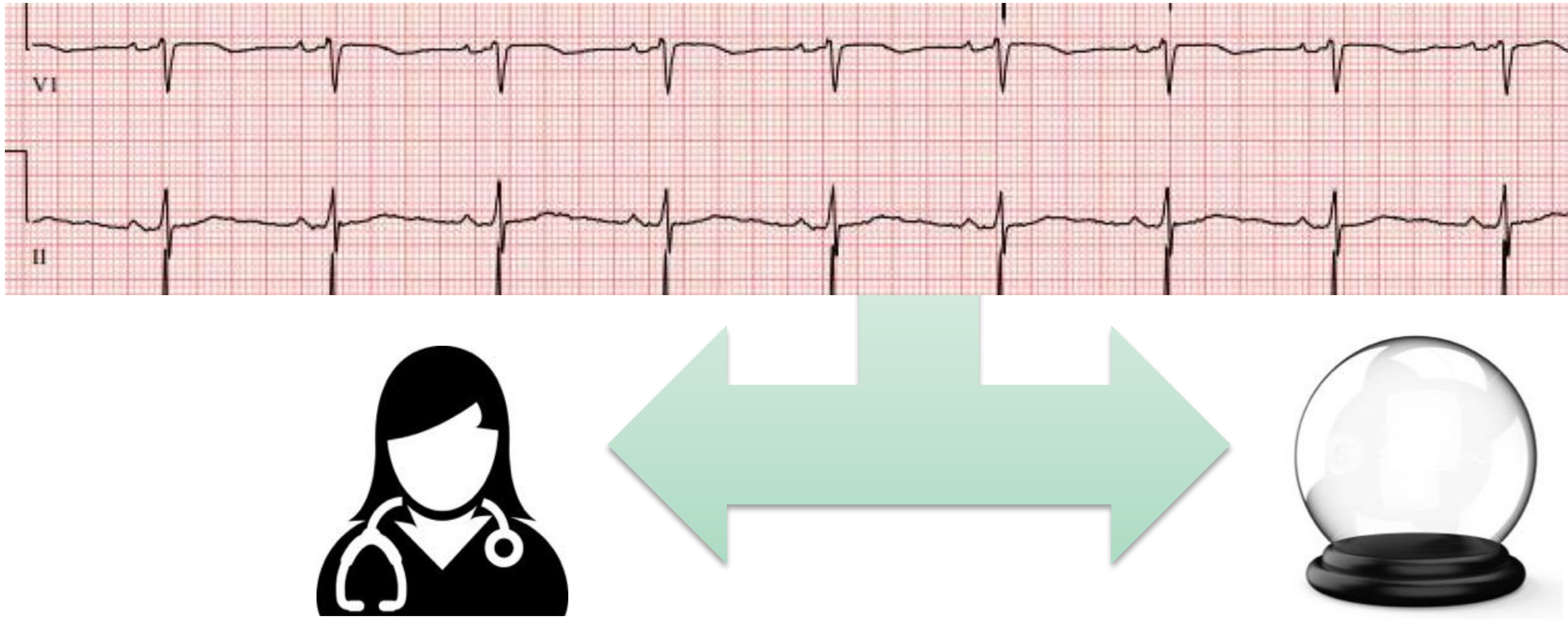
Artificial Intelligence and the 12-lead ECG – Implications for Sleep and Cardiovascular Disease



Virend K Somers
Alice Sheets Marriott Professor
Department of Cardiovascular Medicine
Mayo Clinic

AI-ENHANCED ECG INTERPRETATION

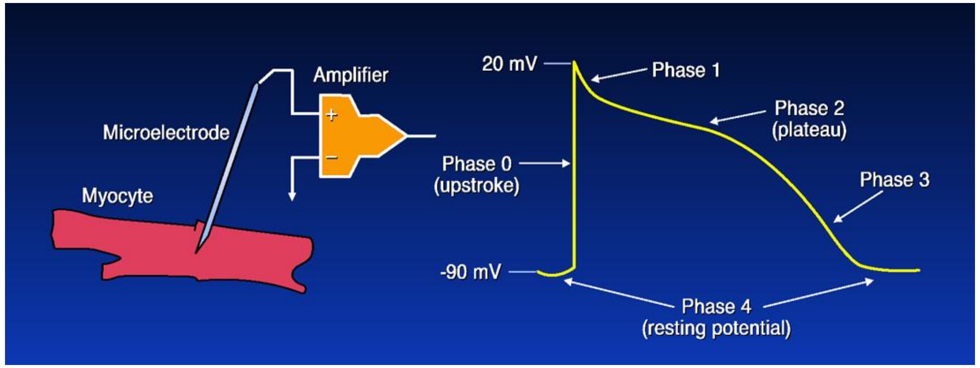


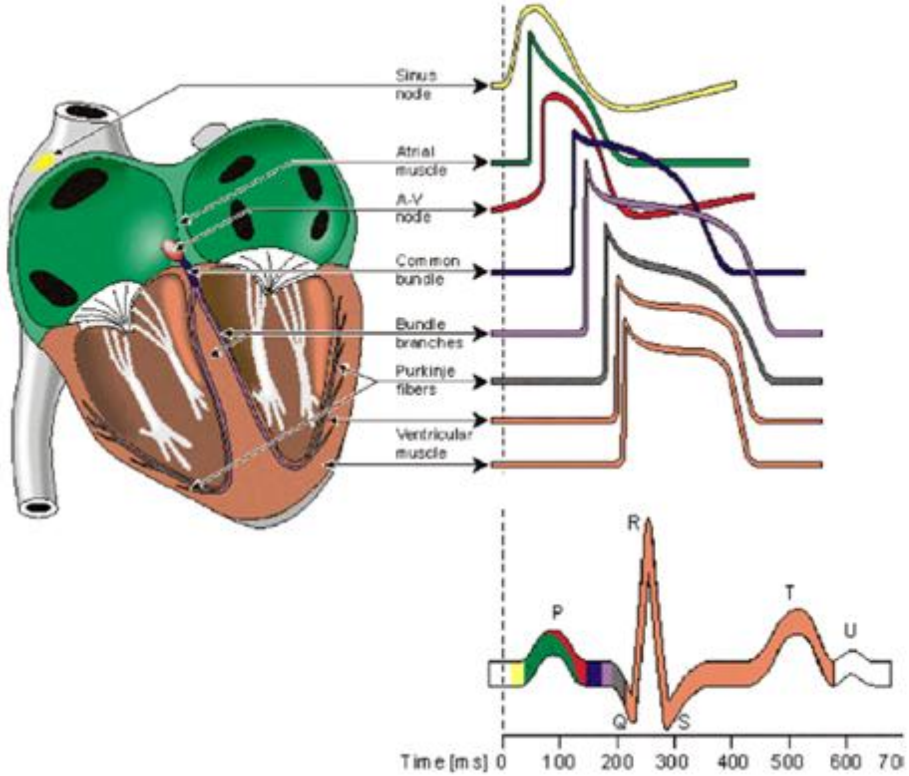
Streamlining ***human*** capability
- First pass interpretation
- Triage work flow
- Scalability

Beyond ***human*** capability
- Seeing what a clinician cannot
- ‘Value-added’ ECG read
- Moving beyond normal/abnormal

ECG Introduction

- Electrocardiography (ECG) is the recording of the heart electrical activity.

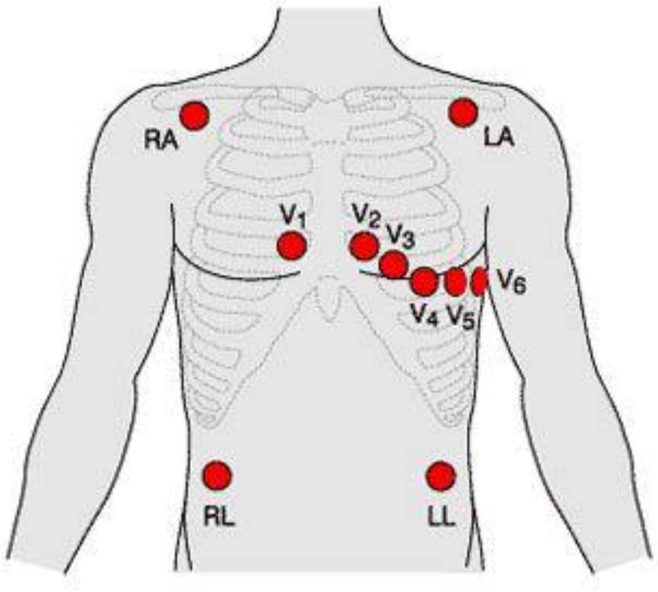


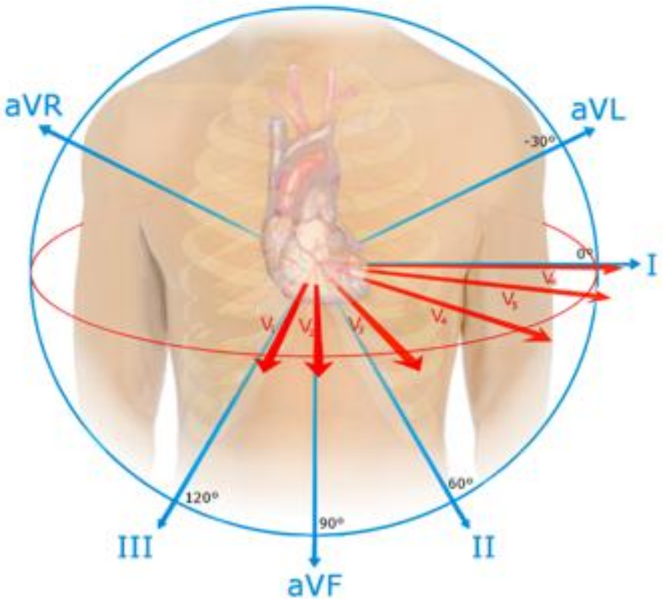


Figures adapted from Jaakko Malmivuo & Robert Plonsey: Bioelectromagnetism

ECG Introduction

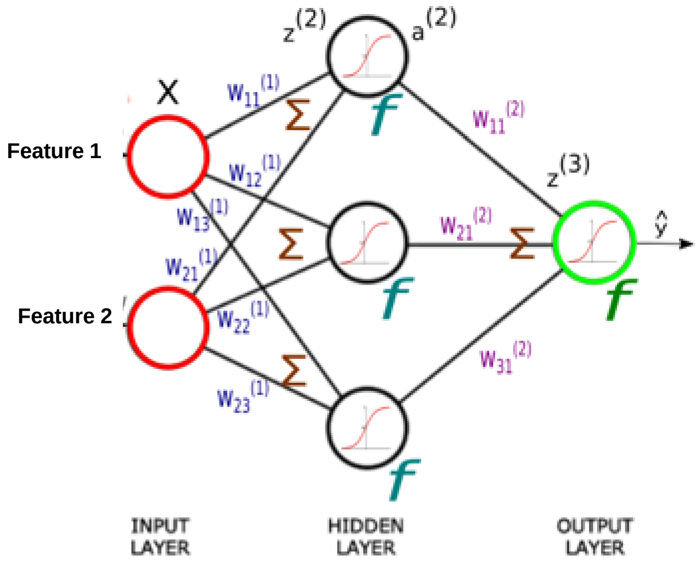
- Each ECG lead presents the projection of the electrical field in different direction
- In typical 12 lead ECG we get information in two planes.

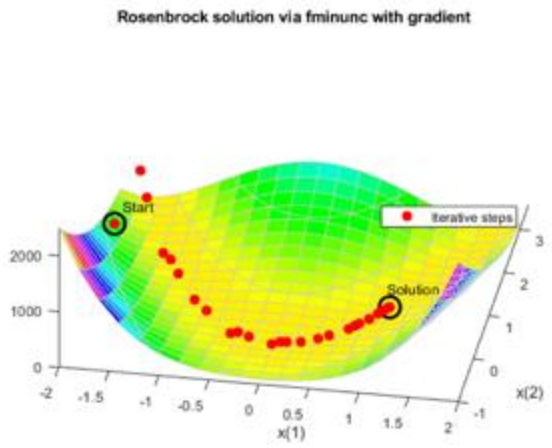




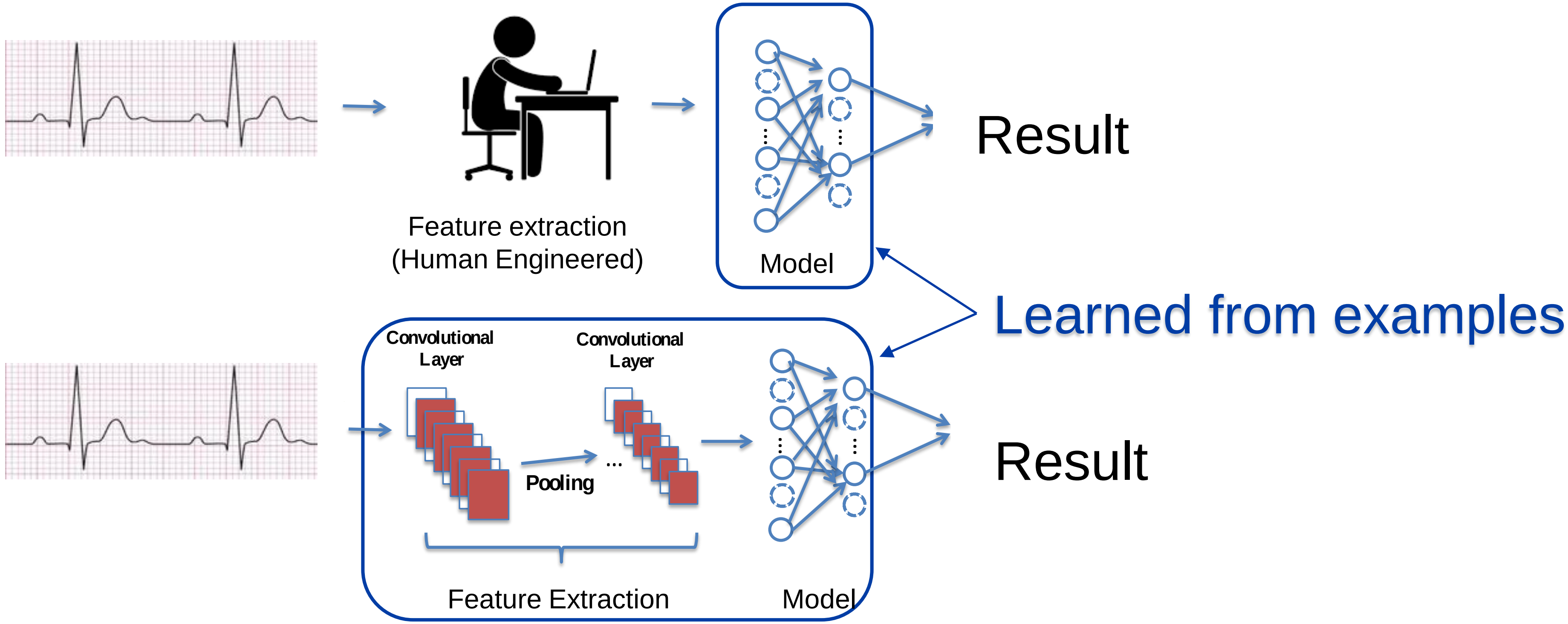
Can We Use ECG for Screening?

- A clinician cannot assess EF from an ECG
- Can an AI model?





Machine Learning vs Deep Learning



“Deep Learning”

nature medicine

Letter | Published: 07 January 2019

Screening for cardiac contractile dysfunction using an artificial intelligence–enabled electrocardiogram

Zachi I. Attia, Suraj Kapa, Francisco Lopez-Jimenez, Paul M. McKie, Dorothy J. Ladewig, Gaurav Satam, Patricia A. Pellikka, Maurice Enriquez-Sarano, Peter A. Noseworthy, Thomas M. Munger, Samuel J. Asirvatham, Christopher G. Scott, Rickey E. Carter & Paul A. Friedman

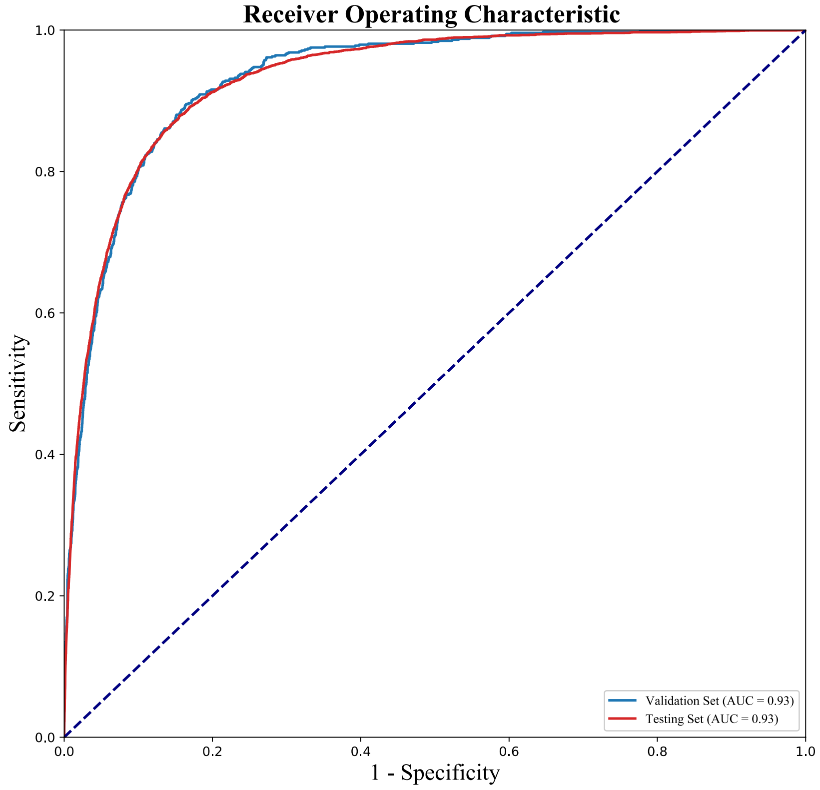
Nature Medicine **25**, 70–74(2019) | Cite this article

Results

Area Under ROC Curve (AUC) was selected to evaluate the model

Similar ROC for validation and hold out data

- ***AUC of EF network = 0.93*** (perfect test = 1.0)
  - ***Sensitivity = Specificity = 86%***
- Compares favorably with other medical tests:
  - Mamography for breast cancer = 0.85
  - Cervical cytology (Pap smear) = 0.70
  - PSA (prostate cancer) = 0.92



Improving the EF model

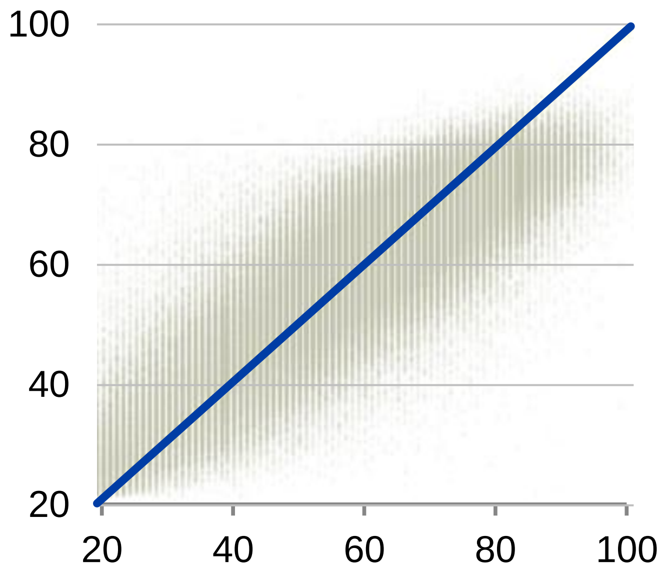
Both age and sex affect systolic function, will adding them as inputs help the model ?

NO

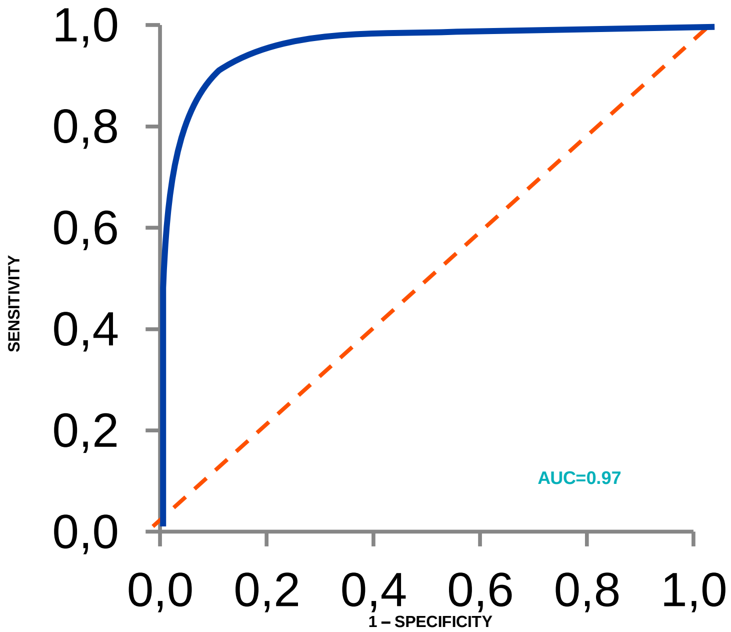
Maybe it can guess it?

Age and Sex from ECG

**“REAL” AGE VS
ECG ESTIMATED AGE**



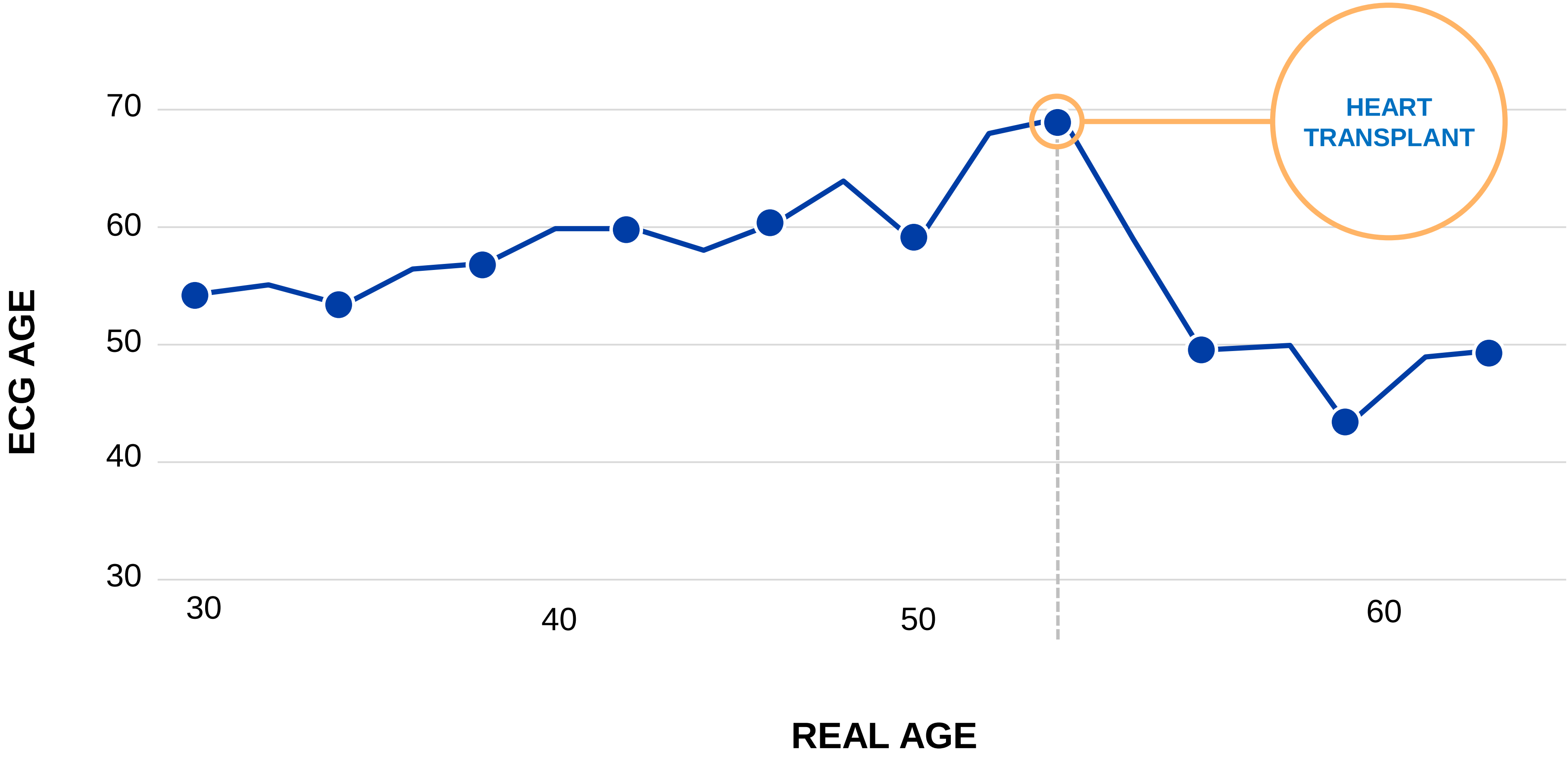
SEX DETECTION FROM ECG



Circulation Arrhythmia and Electrophysiology
JOURNAL OF THE AMERICAN HEART ASSOCIATION
American Heart Association
Learn and Live

Attia et al. 2019

Patient #1 : Progression of ECG Age in a Patient with Multiple ECGs



ORIGINAL ARTICLE

MAYO CLINIC PROCEEDINGS

MAYO CLINIC

Check for updates

Accelerated Aging in *LMNA* Mutations Detected by Artificial Intelligence ECG–Derived Age

Shahar Shelly, MD; Francisco Lopez-Jimenez, MD; Audry Chacin-Suarez, MD; Michal Cohen-Shelly, BSc; Jose R. Medina-Inojosa, MD; Suraj Kapa, MD; Zachi Attia, MD; Anwar A. Chahal, MD; Virend K. Somers, MD; Paul A. Friedman, MD; and Margherita Milone, MD, PhD

Abstract

Objective: To demonstrate early aging in patients with lamin A/C (*LMNA*) gene mutations after hypothesizing that they have a biological age older than chronological age, as such a finding impacts care.

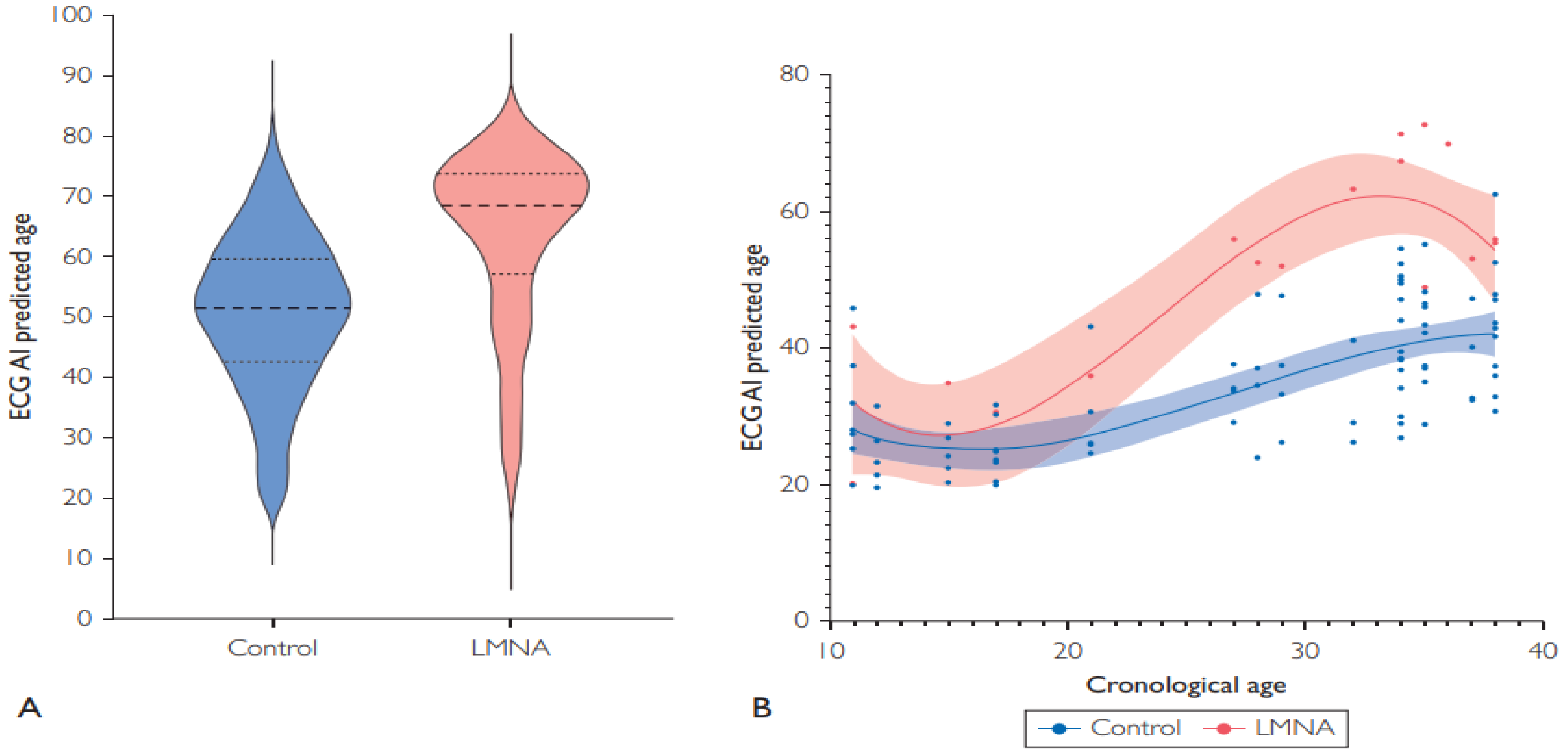


FIGURE 1. Patients with *LMNA* mutation have higher predicted age compared with controls. Comparing our cohort predicted age using whisker plots (A) comparing *LMNA* patients (red) predicted biological vs controls (blue). We show significant difference ($P<.001$) in age predicted by our neural network between the two groups. B, Linear regression analysis comparing *LMNA* patients (upper line, red dots) vs controls (lower line, blue dots), plotting predicted age vs chronological age. We show higher predicted age compared with chronological age in *LMNA* patients compared with controls. AI, artificial intelligence; ECG, electrocardiogram; *LMNA*, lamin A/C gene.

Accelerated Biological Aging in Patients with Lamin A/C Gene Mutations

Shelly et al, *Mayo Clin Proc* 2023

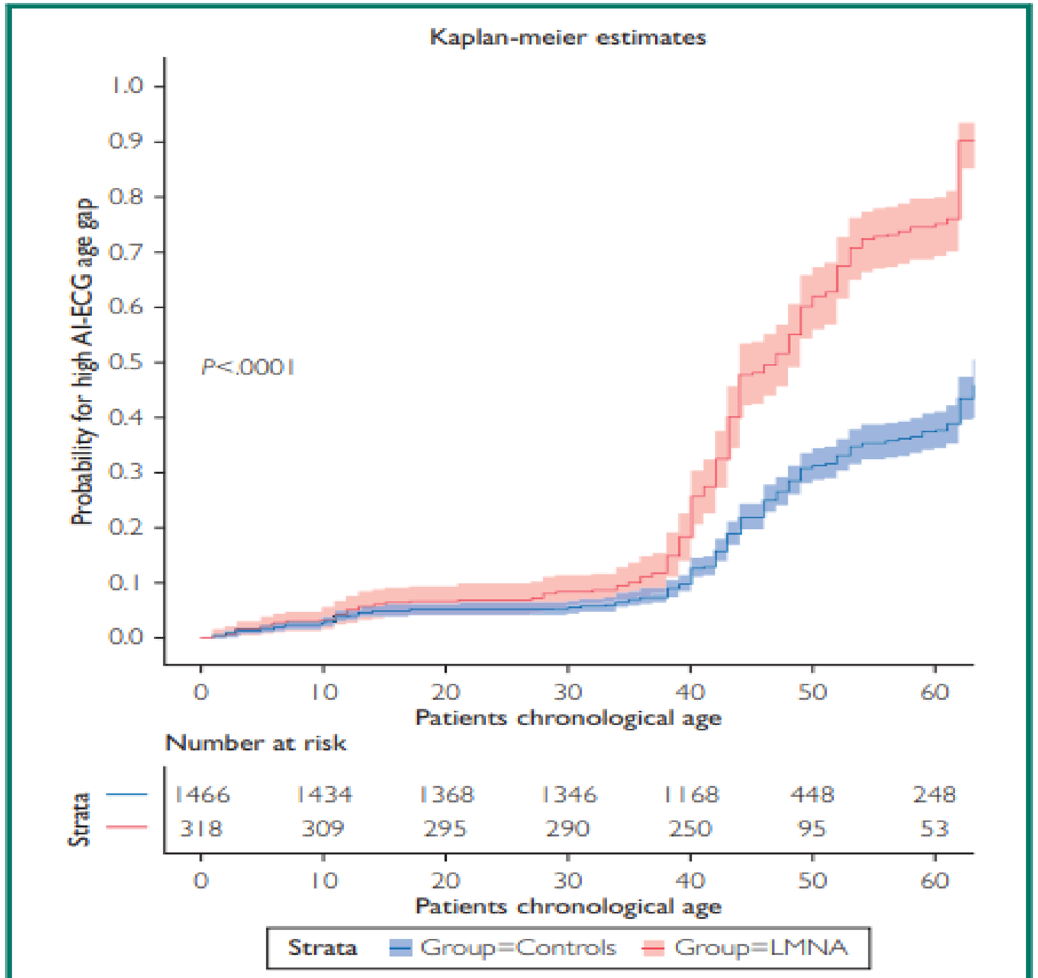
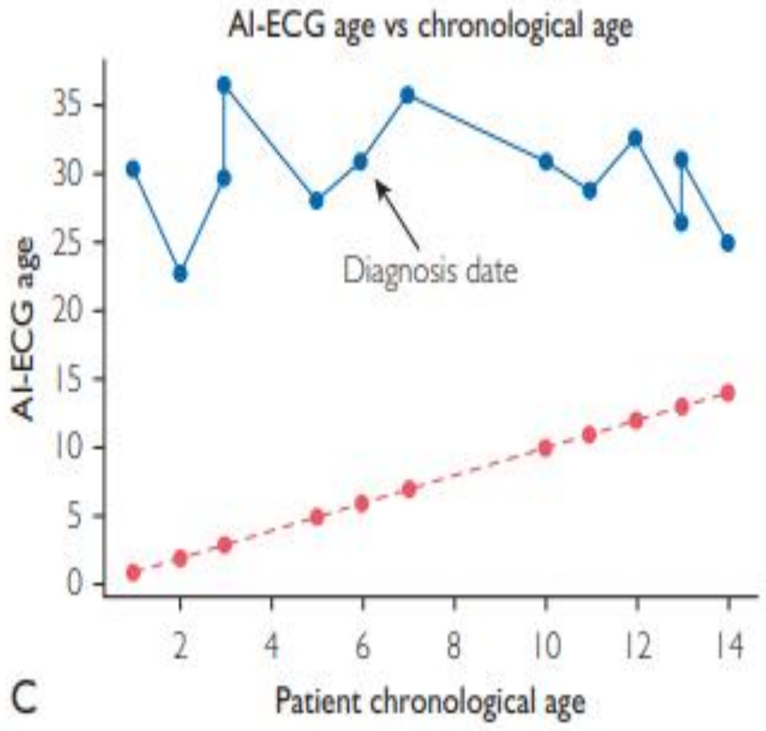
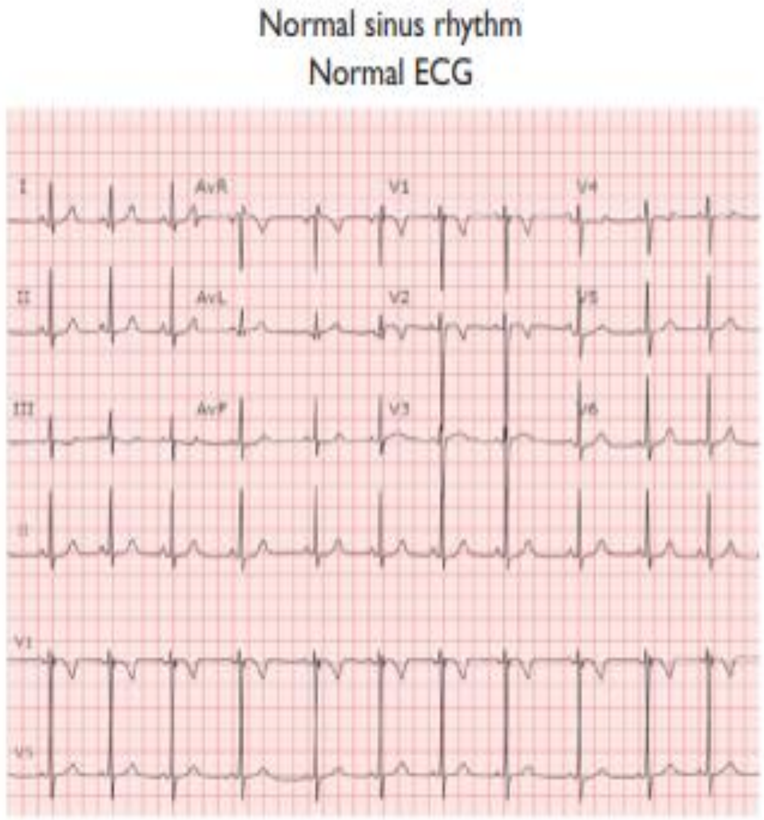


FIGURE 2. Accelerated aging in patients with lamin A/C gene (*LMNA*) mutation. To better appreciate change of age over time, we investigated acceleration of "biological aging" in all *LMNA* patients (red) compared with controls (blue). All patients' and controls' artificial intelligence electrogram (AI-ECG)—predicated ages are represented with a cumulative analysis plot vs chronological age. Each *LMNA* patient's ECG was matched with ECG from five controls. The informative risk table set (bottom) displays the number of patients that were under observation in the specific age period.

Patient #2 - Serial ECGs in a patient with lamin A/C mutation



C



D

Hypertrophic Cardiomyopathy

Matching

Age and sex match

HCM (n=3,060)

Controls (n=63,941)

Model dev (70:10:20)

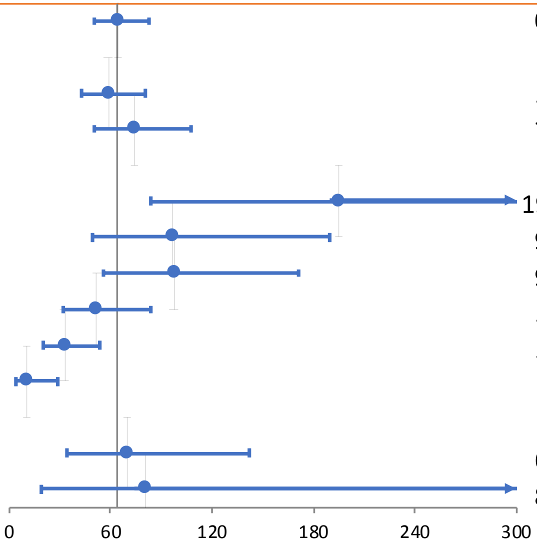
Training (n=46,901)
HCM (n=2,142)
Controls (n=44,759

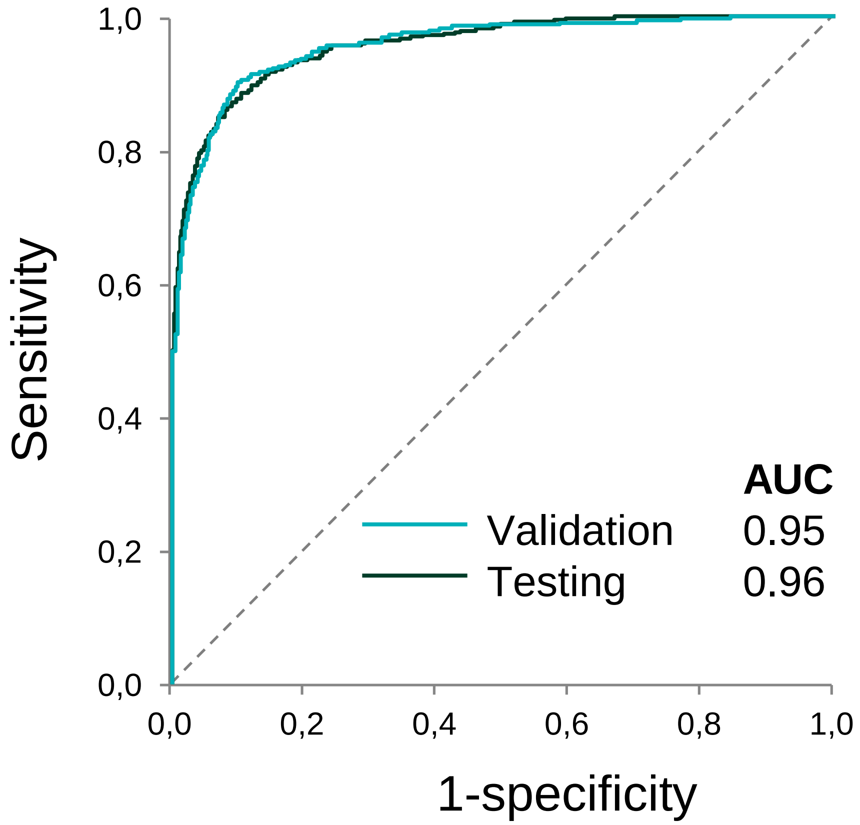
Validation (n=6,700)
HCM (n=306)
Controls (n=6,394)

Testing (n=13,400)
HCM (n=612)
Controls (n=12,788)

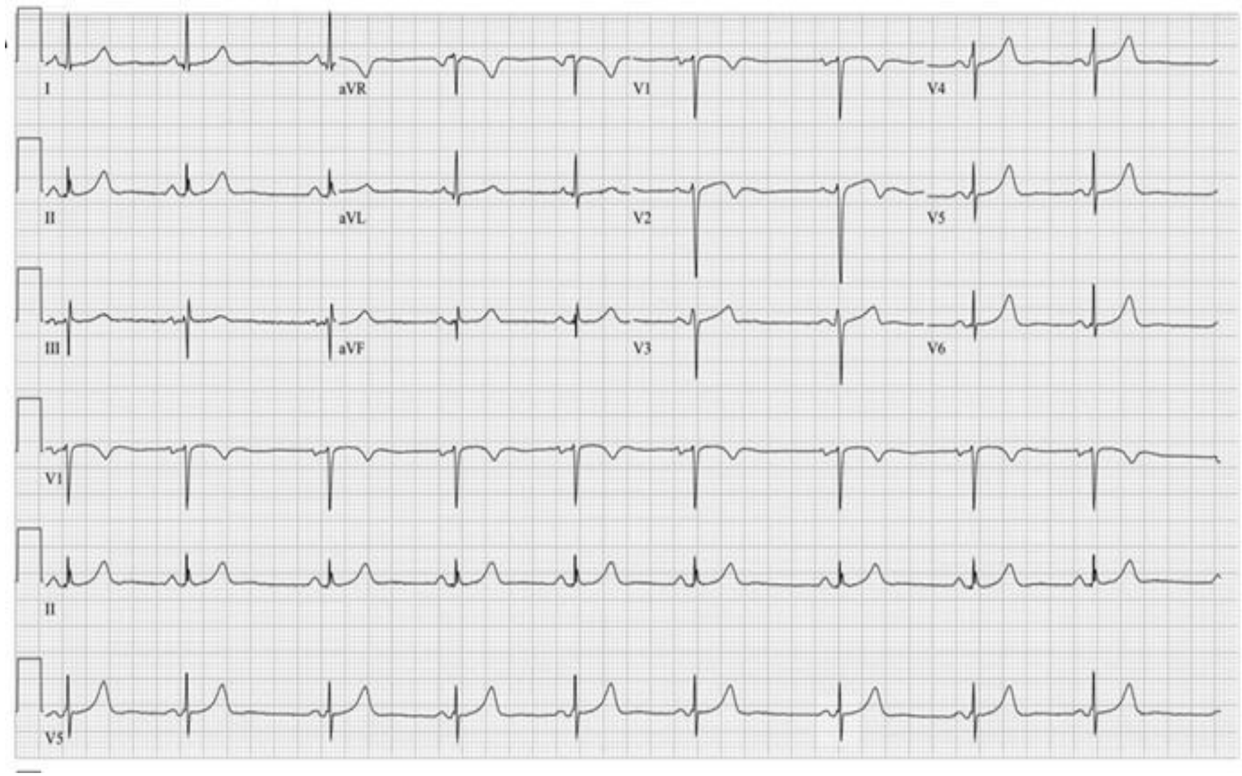
HCM - Results

Group	Sensitivity	Specificity	Odds Ratio	OR (95% CI)
Overall	**87 (534/612)**	**90 (11562/12788)**		**64.6 (50.5-82.5)**
Sex				
Male	87 (301/346)	90 (6518/72662)		58.6 (42.5-80.9)
Female	88 (233/266)	91 (5044/5526)		73.9 (50.7-107.7)
Age (yrs)				
<40	95 (108/114)	92 (1636/1787)		195.0 (84.3-451.2)
40-49	90 (92/102)	91 (1546/1693)		96.8 (49.3-189.9)
50-59	90 (125/139)	92 (2627/2868)		97.3 (55.2-171.7)
60-69	84 (112/133)	91 (3130/3452)		51.8 (32.1-83.8)
70-79	80 (83/104)	89 (2151/2412)		32.6 (19.8-53.5)
≥80	70 (14/20)	82 (472/576)		10.6 (4-28.2)
ECG characteristics				
LVH	97 (263/271)	68 (805/1184)		69.8 (34.2-142.6)
Normal ECG	93 (25/27)	87 (361/417)		80.6 (18.6-349.6)



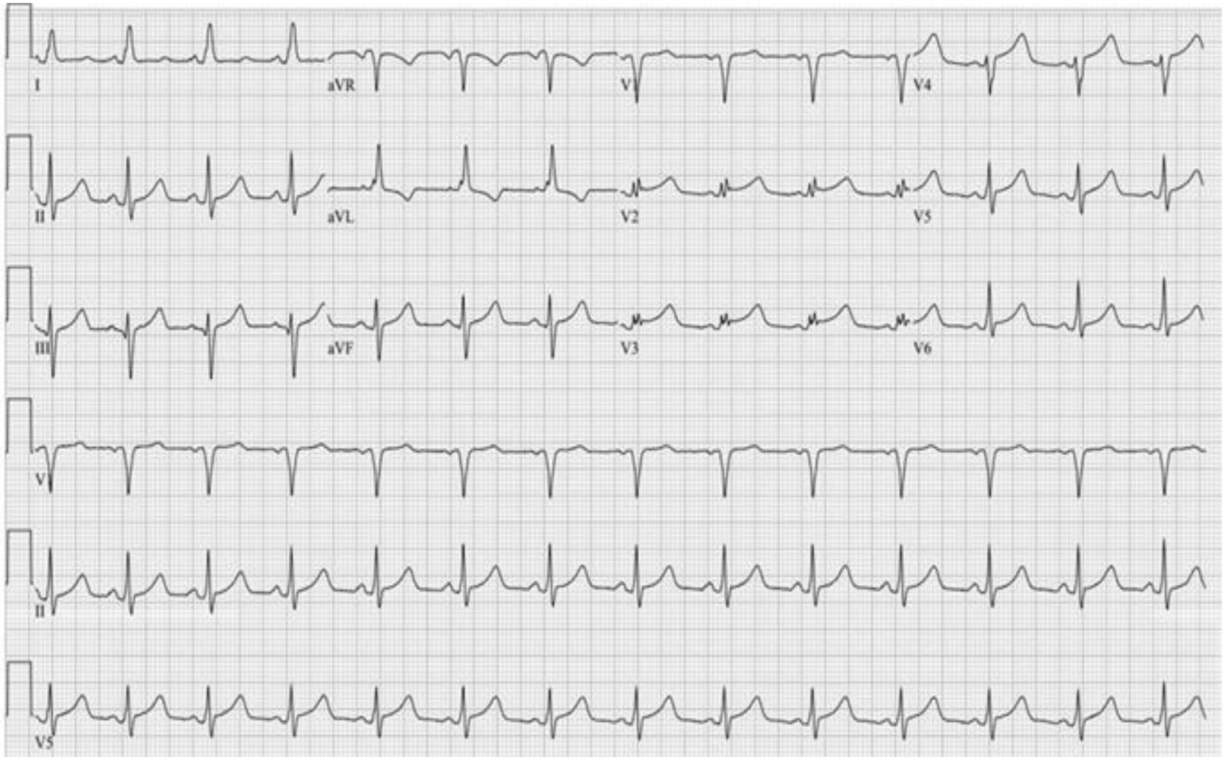


Patient #3: 25-year-old woman with HCM



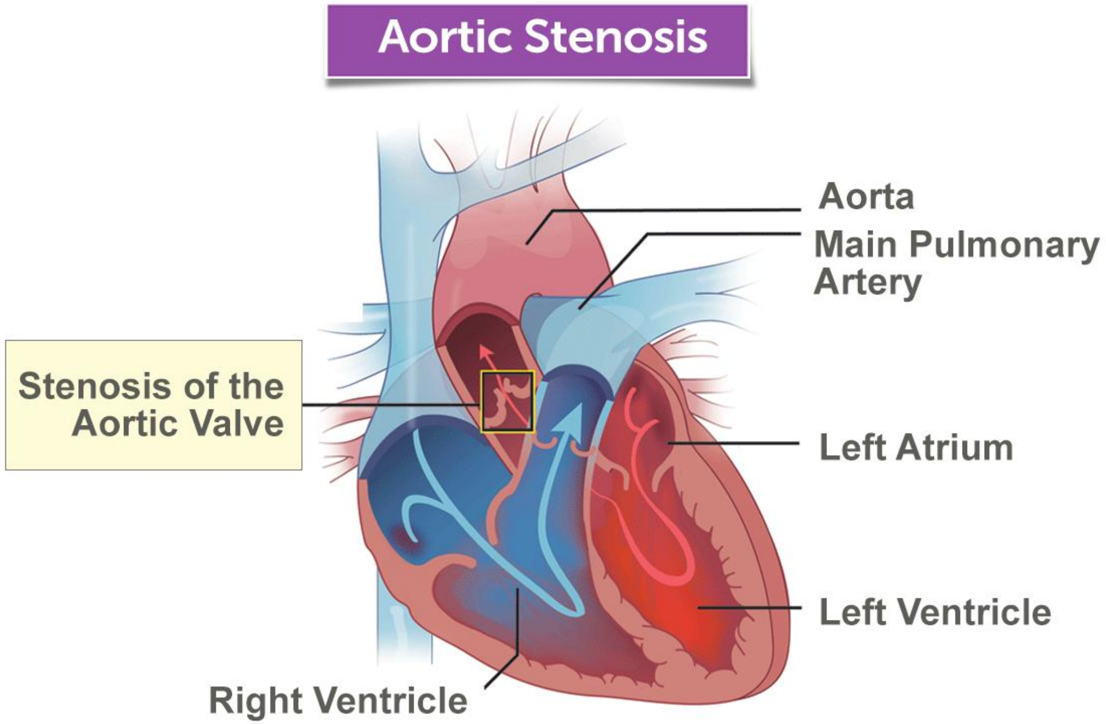
72.6% probability of HCM!

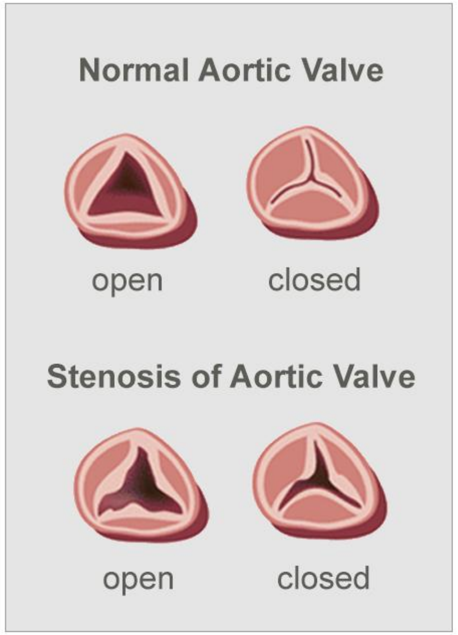
Post-op: Patient undergoes septal myectomy



ECG becomes more 'abnormal' but now AI calculates a 2.5% probability of HCM!

Detection of Aortic Stenosis



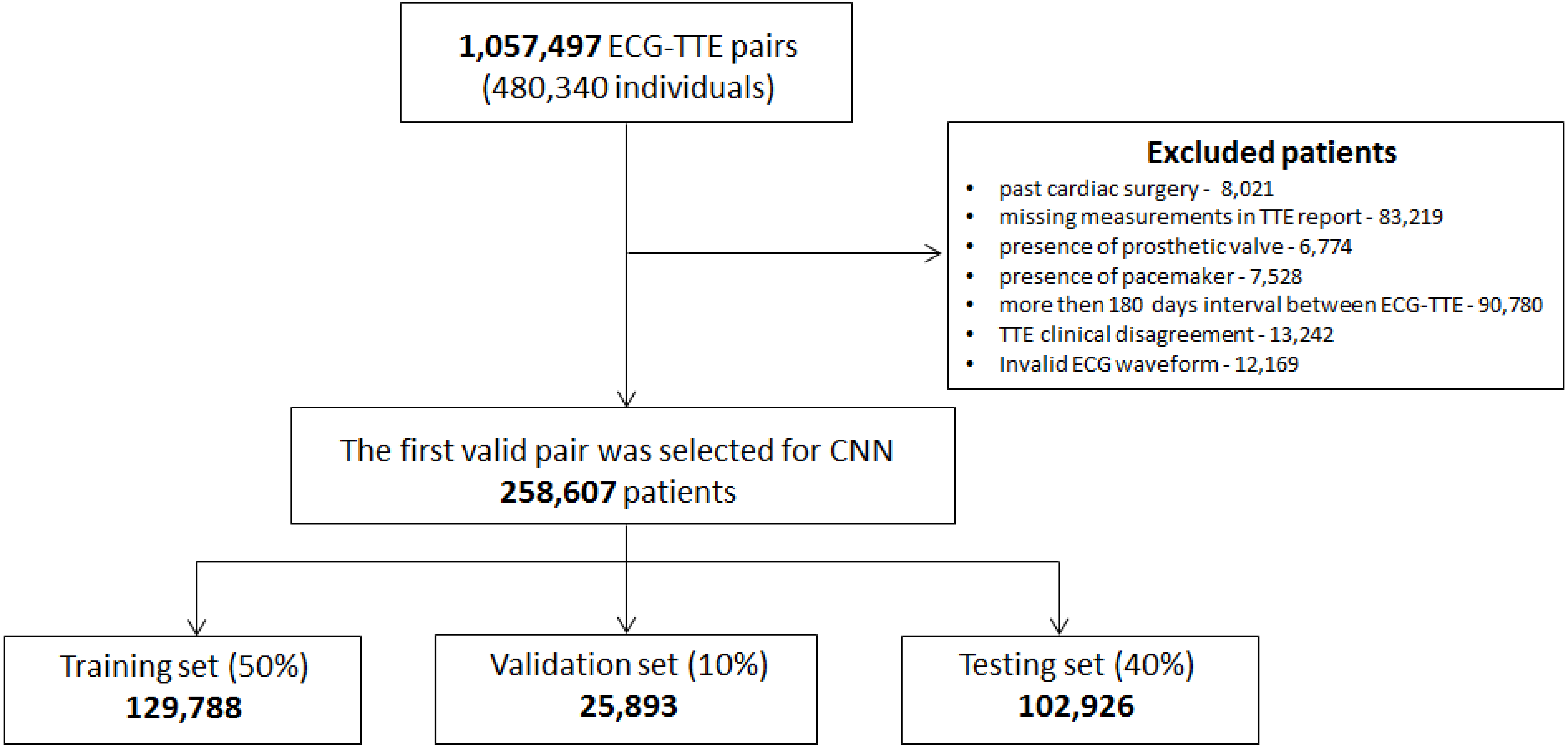


Shelly-Cohen et al. (In review - *JACC*

Methods - Labeling Definitions

	AS (-)		AS (+)	
	Normal	**Mild**	**Moderate**	**Severe**
Aortic Valve Area (cm^2)	2 or higher	(1.5-2.0)	[1.0 -1.5]	below 1.0
AV Velocity (m/sec)	2.5 or below	(2.5 -3.0)	[3.0 – 4.0)	4 or higher
AV Mean Gradient (mmHg)	10 or below	(10 – 20)	[20 – 40)	40 or higher
Doppler Velocity Index	0.5 or higher	(0.35 – 0.5)	[0.25 -0.35]	Below 0.25

Methods - Cohort Definitions

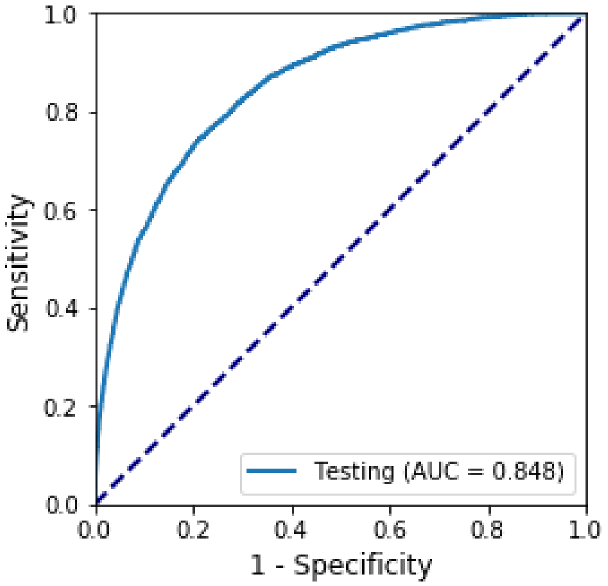


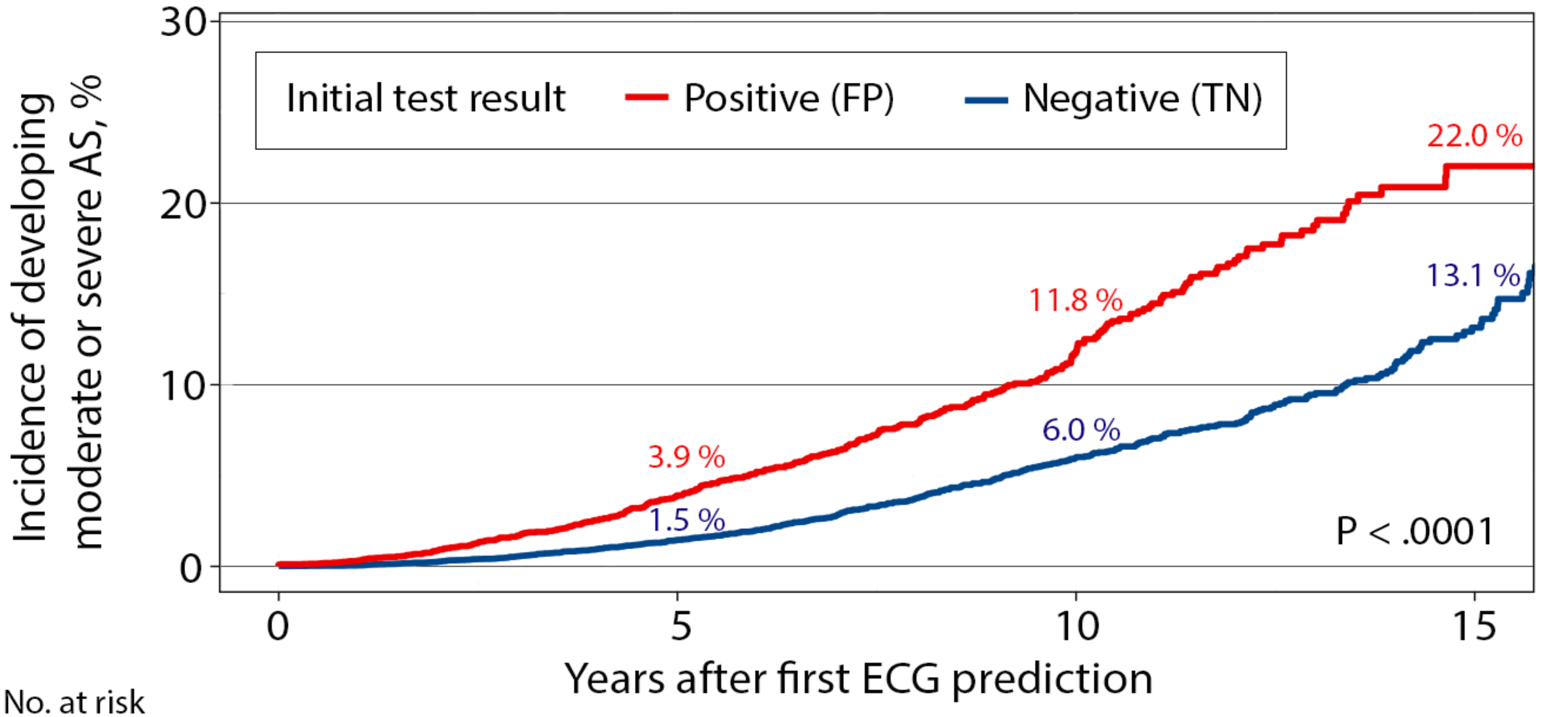
Results

Area Under the Curve : **0.848**

Sensitivity: **78.1%**

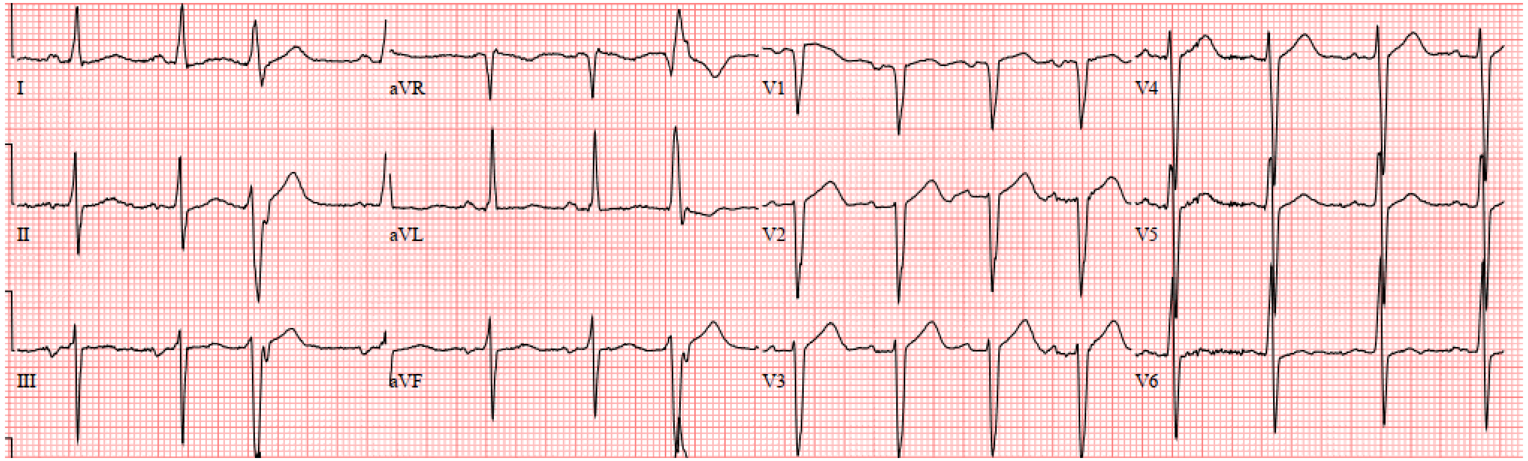
Specificity: **74.3%**

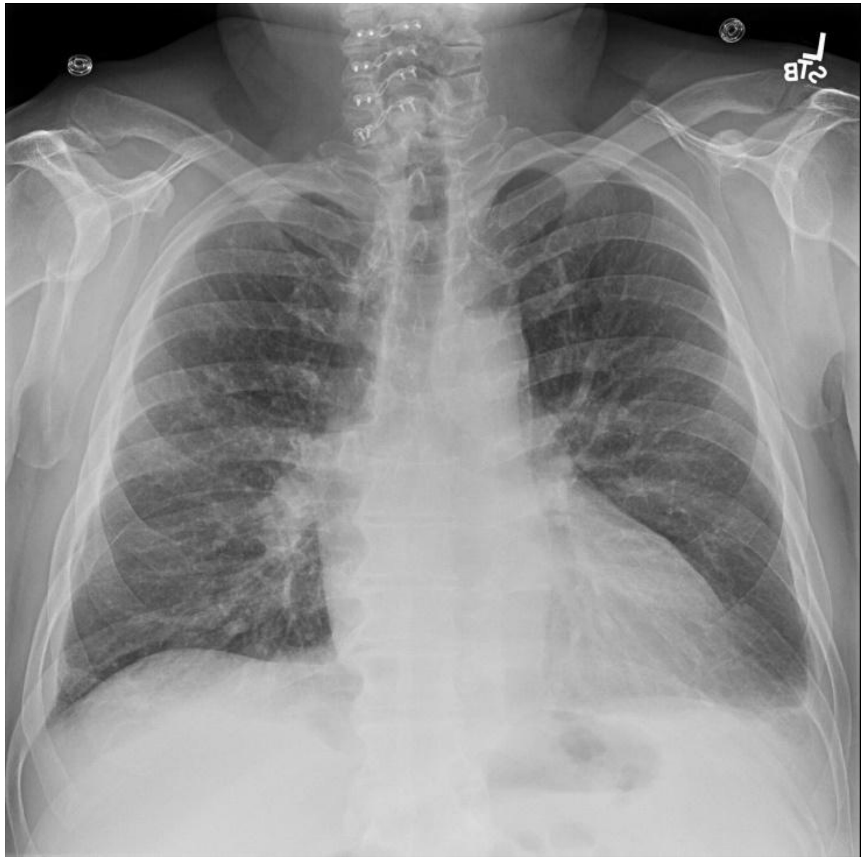




No. at risk				
Positive (FP)	8474	2880	793	102
Negative (TN)	20718	7969	2654	382

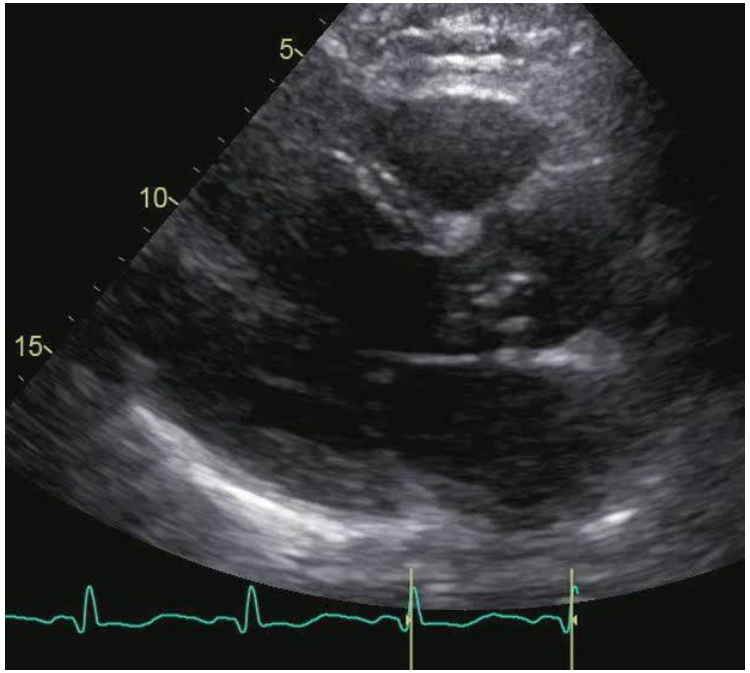
Case #4 :67 year old man presented with increasing dyspnea

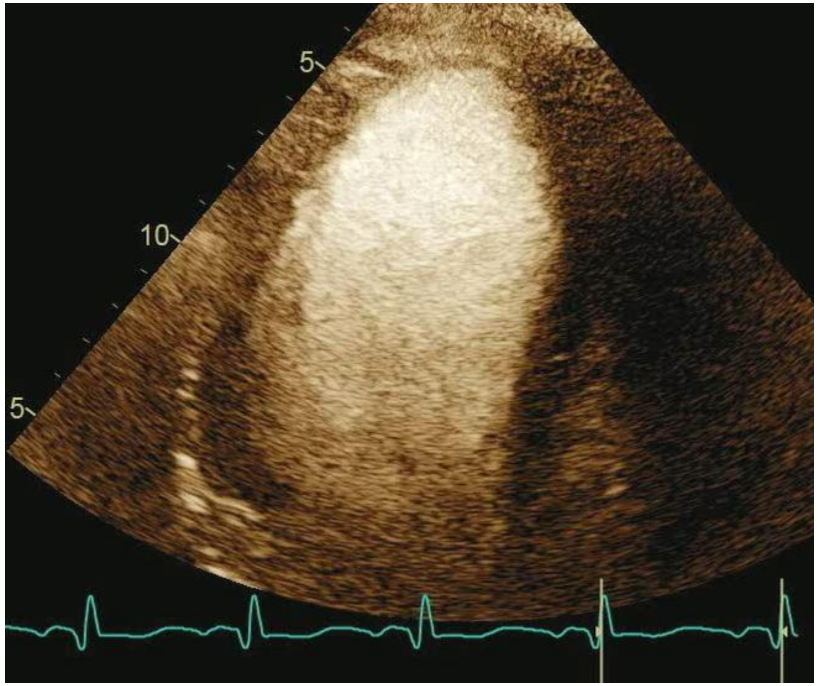


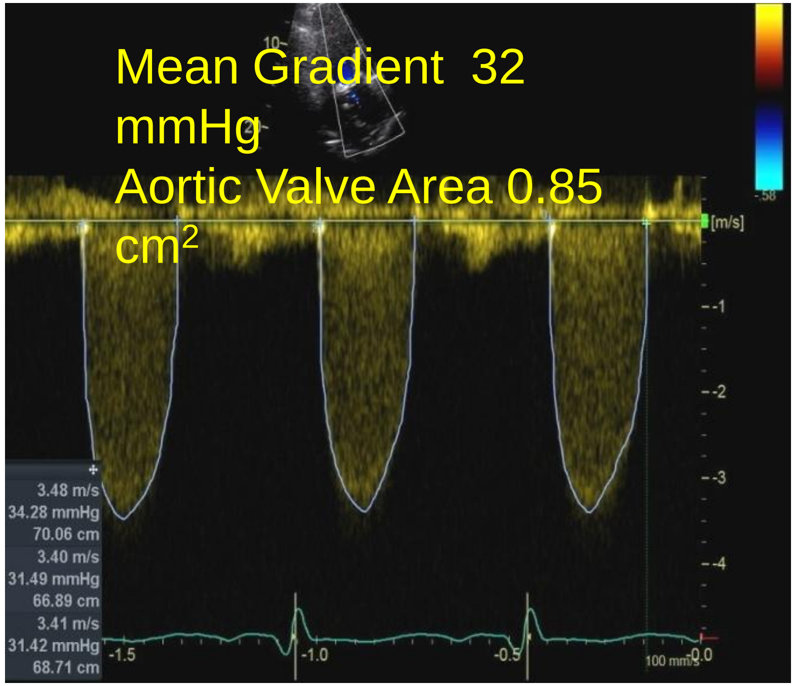


Positive for AS

67 year old man presented with heart failure
Severe Aortic Stenosis with reduced LV ejection fraction

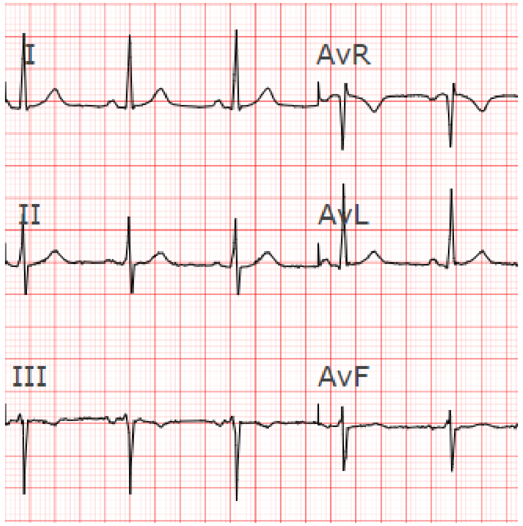


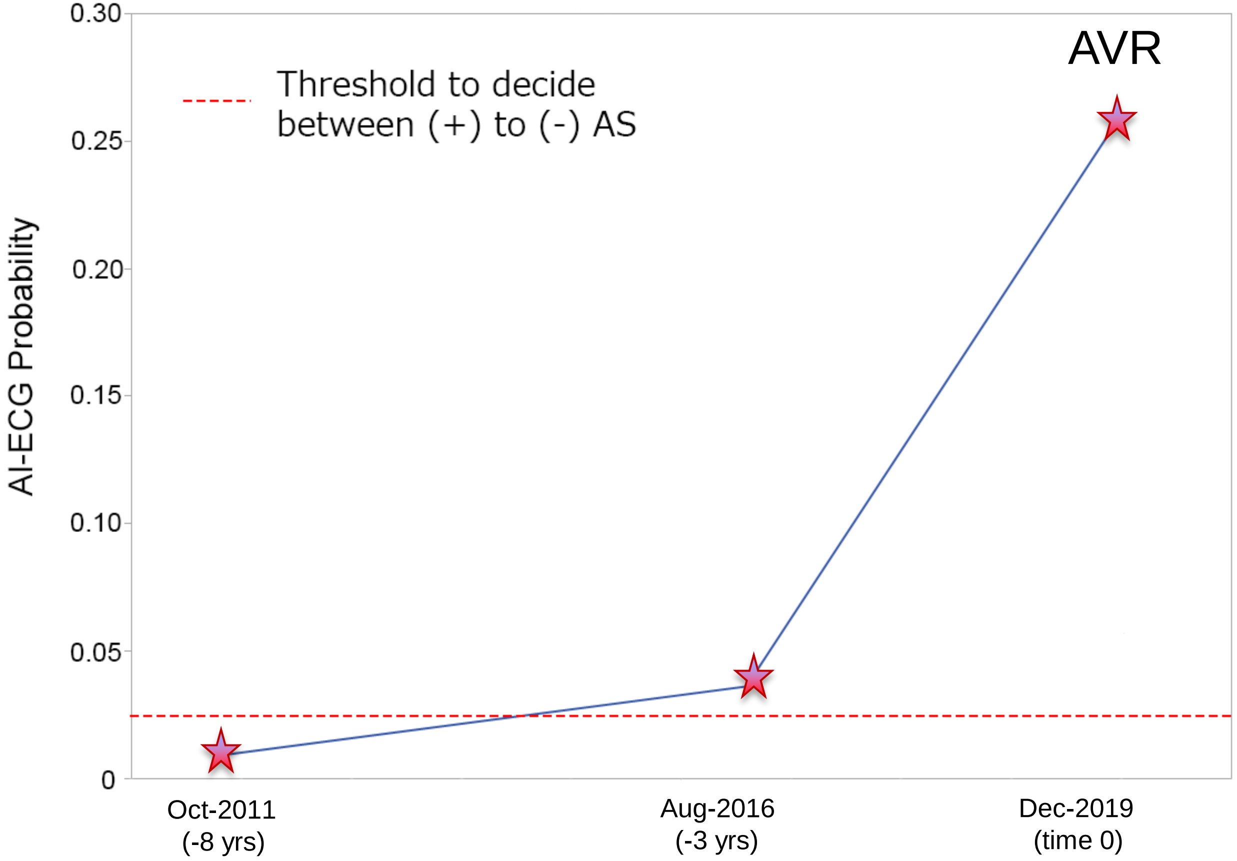


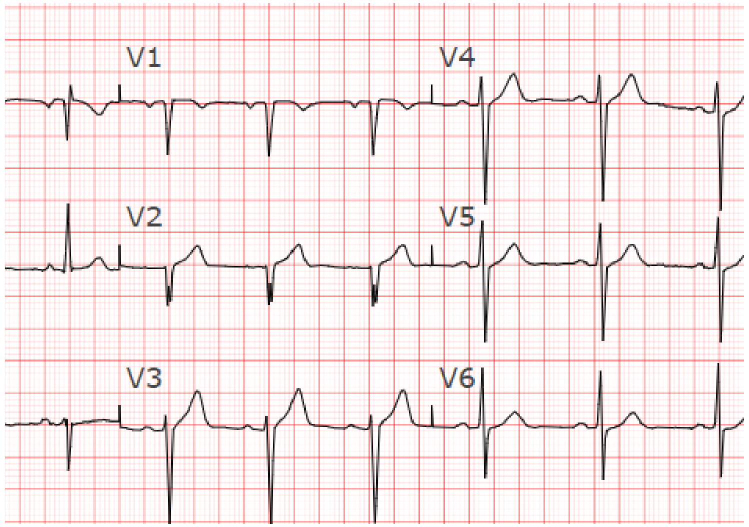


67 year old man with heart failure and severe aortic stenosis ECGs change

2011 (… 3 years earlier)







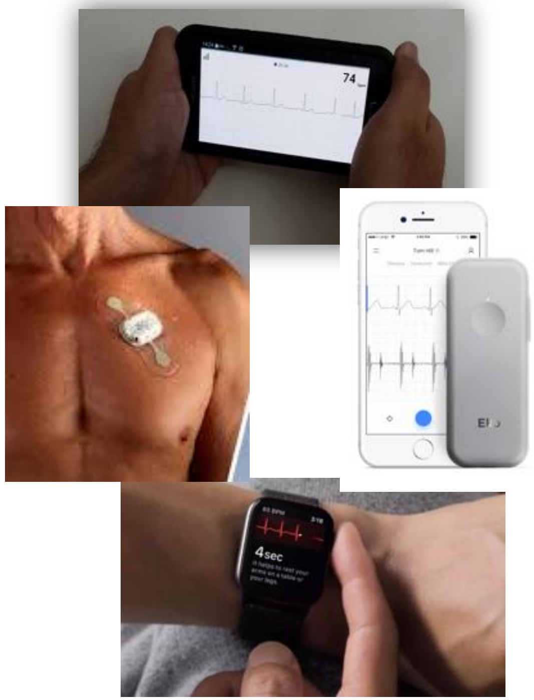
AI-EC … CG → **AS (+)**

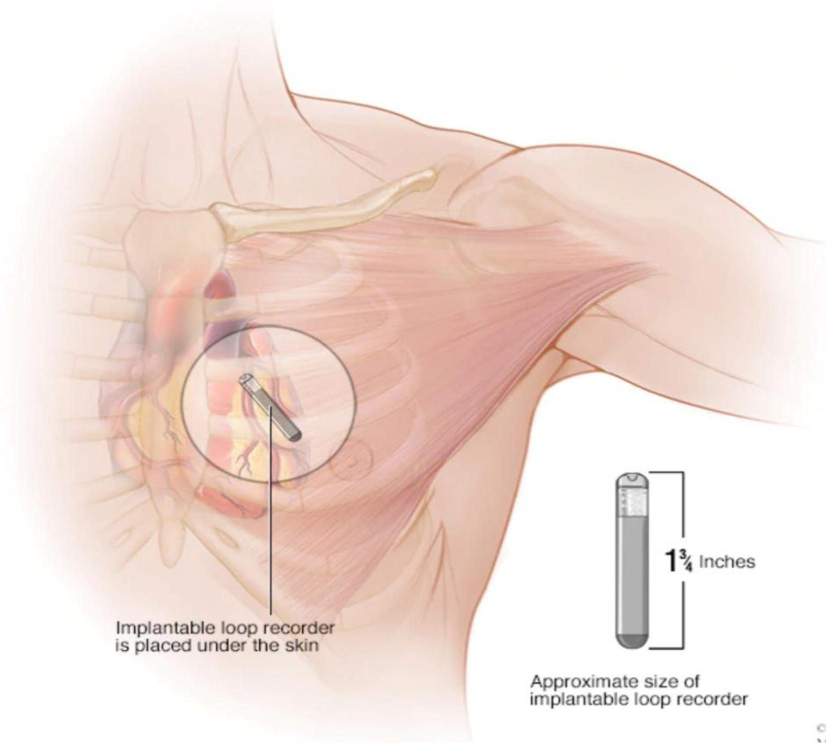
Screening for Paroxysmal Atrial Fibrillation

- Often fleeting
- Sometimes asymptomatic
- Can have major consequences: Stroke

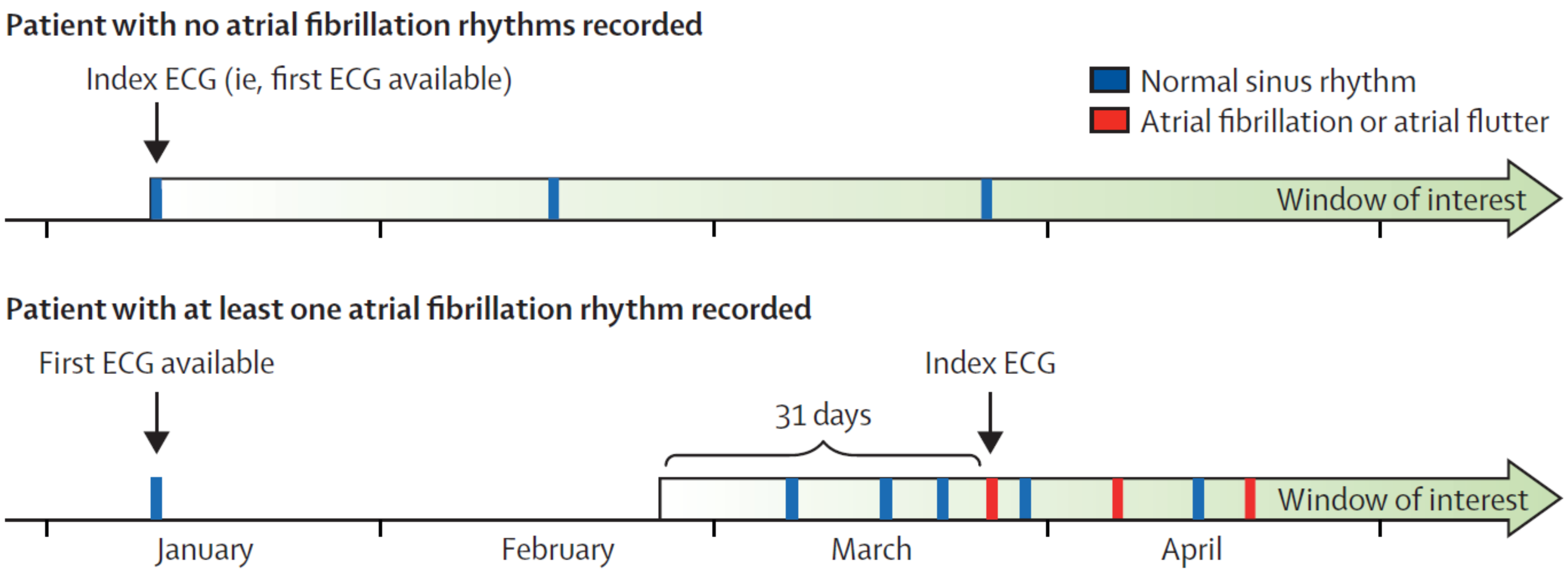
Continuous Monitoring vs Mobile Form Factors

Will short episodes, detected with continuous or near continuous monitoring have the same prognostic significance?





Scanning ECGs in NSR to Determine if AF <u>was</u> Present in the Past!

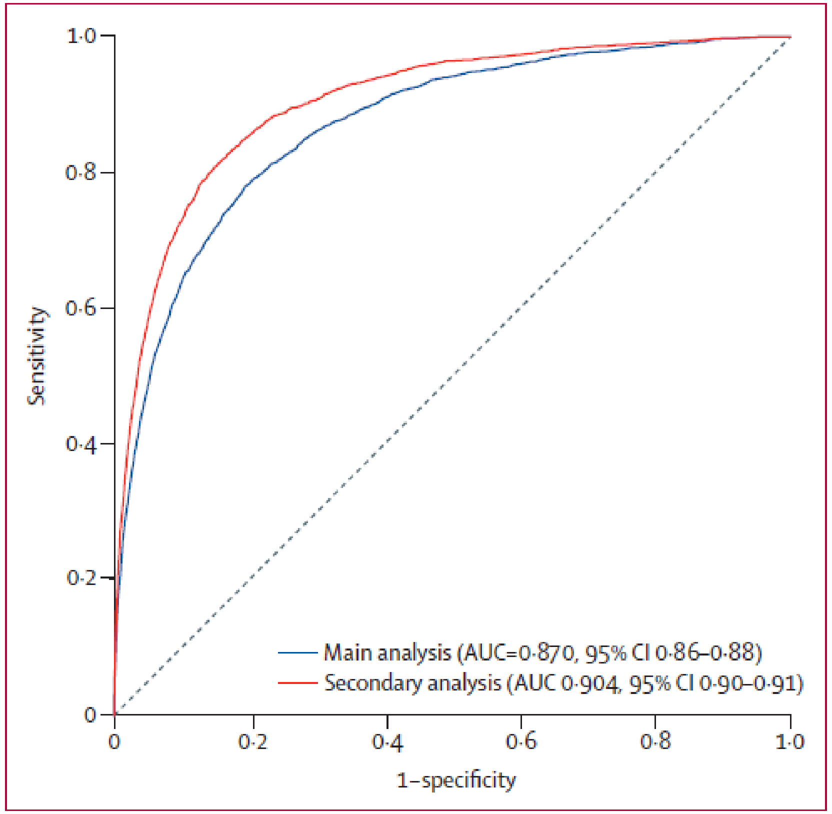


Only Normal Sinus ECGs were used !

THE LANCET *Attia et al. 2019*

MAYO CLINIC

Results- AF Screening



	AUC	Sensitivity	Specificity
Primary	0.87	79·0%	79·5%
Secondary	0.90	82·3%	83·4%

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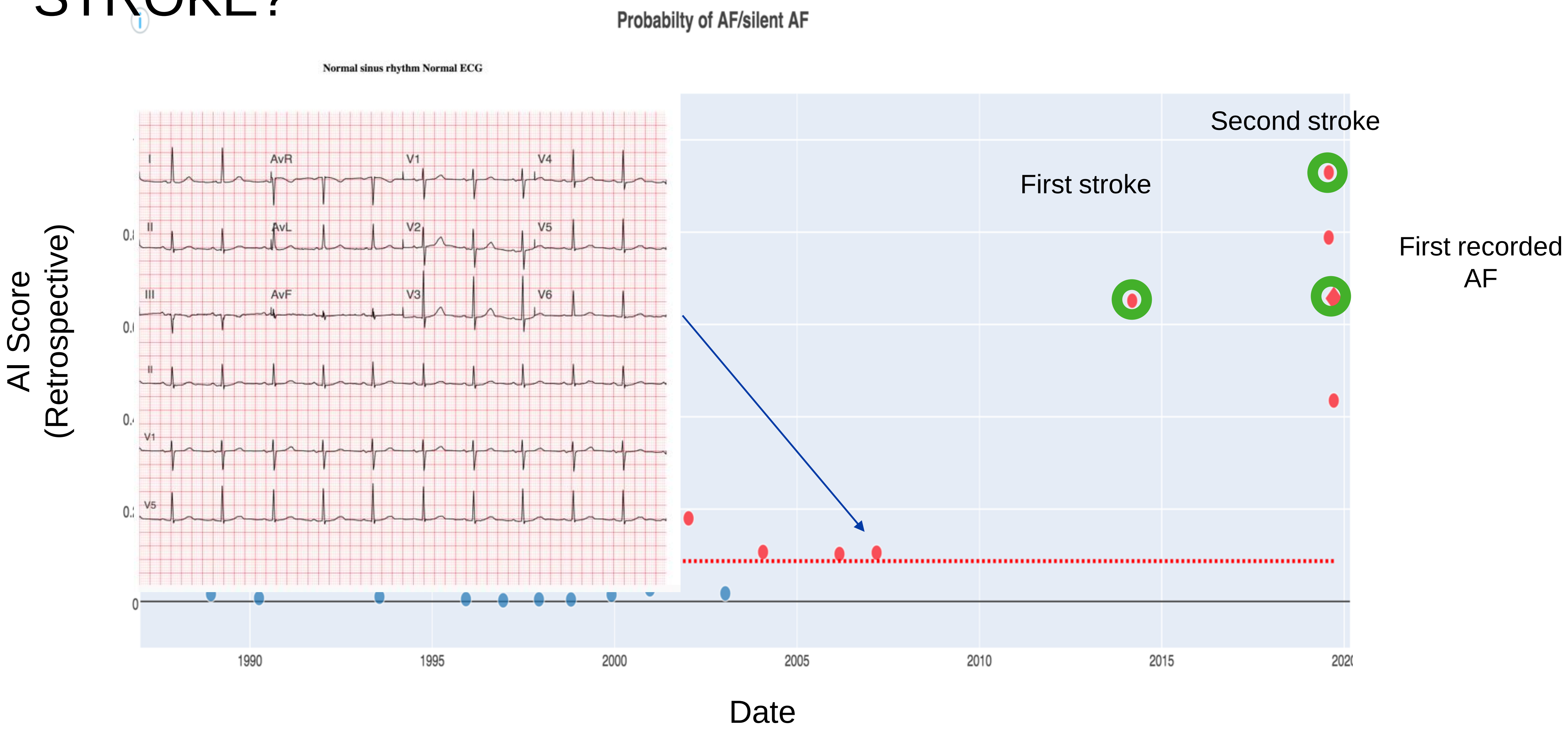
CASE #5 : COULD AI HAVE PREVENTED A STROKE?



Common Risk Factors for CVD and for Sleep Apnea

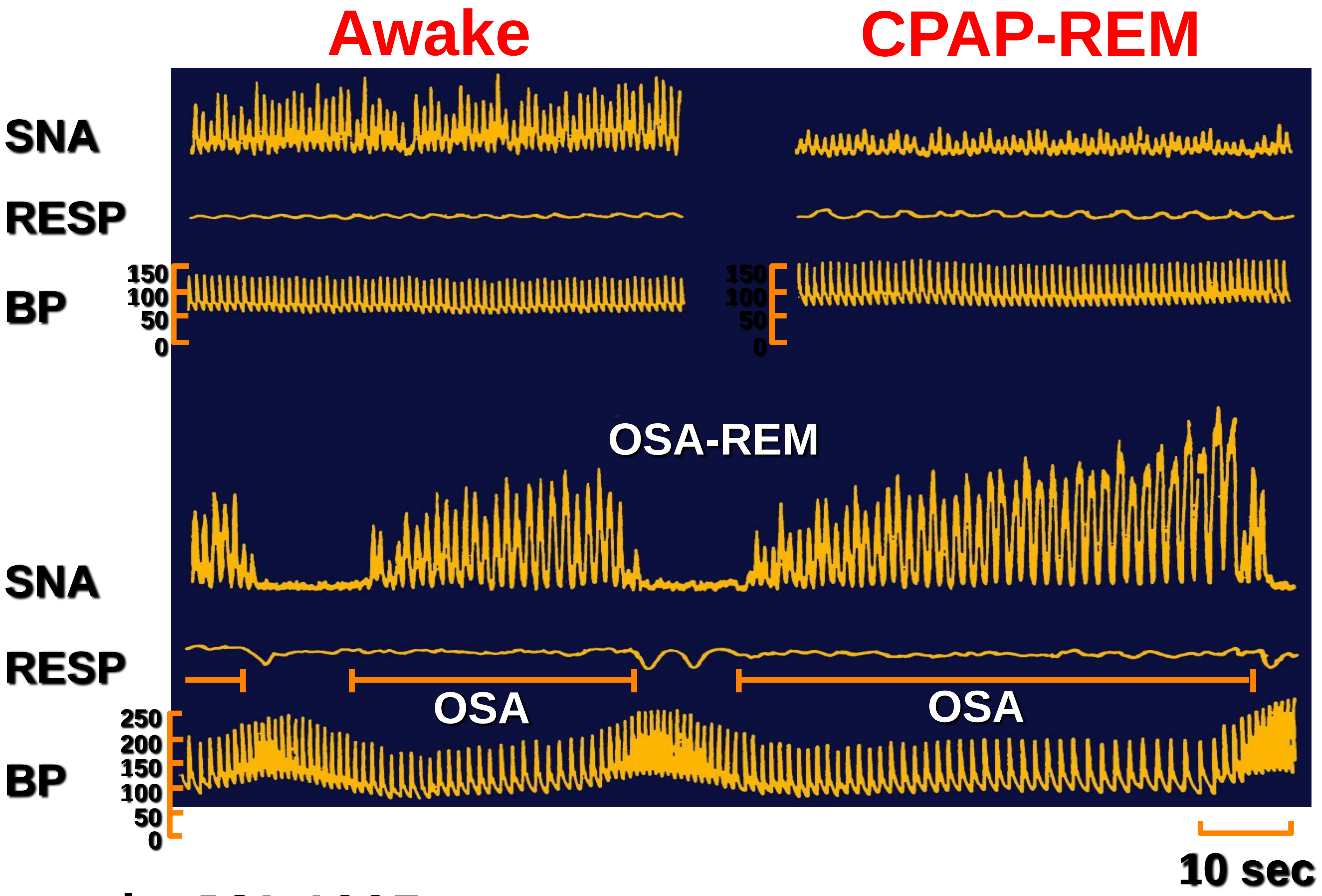
Older Age

Male Sex

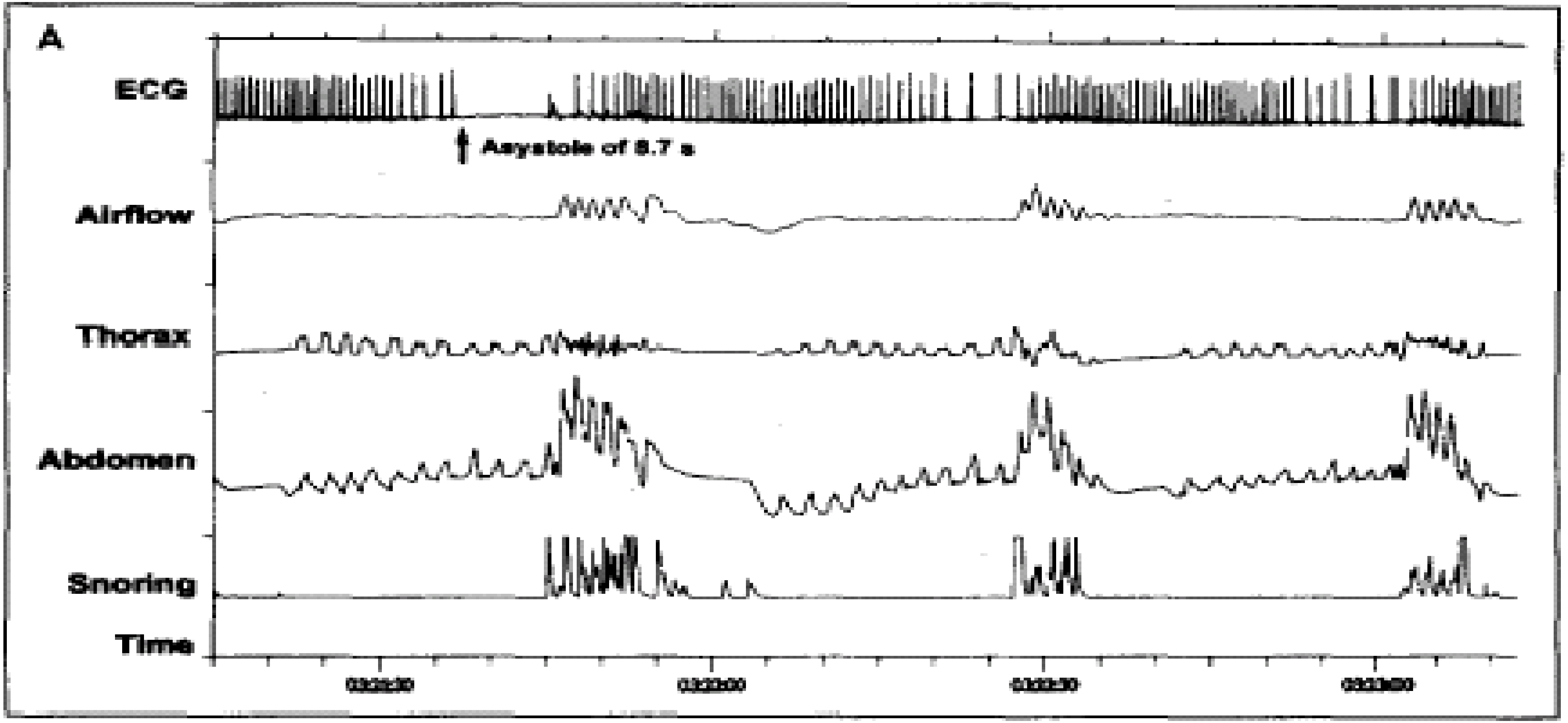
Obesity

Hypertension

Atrial Fibrillation



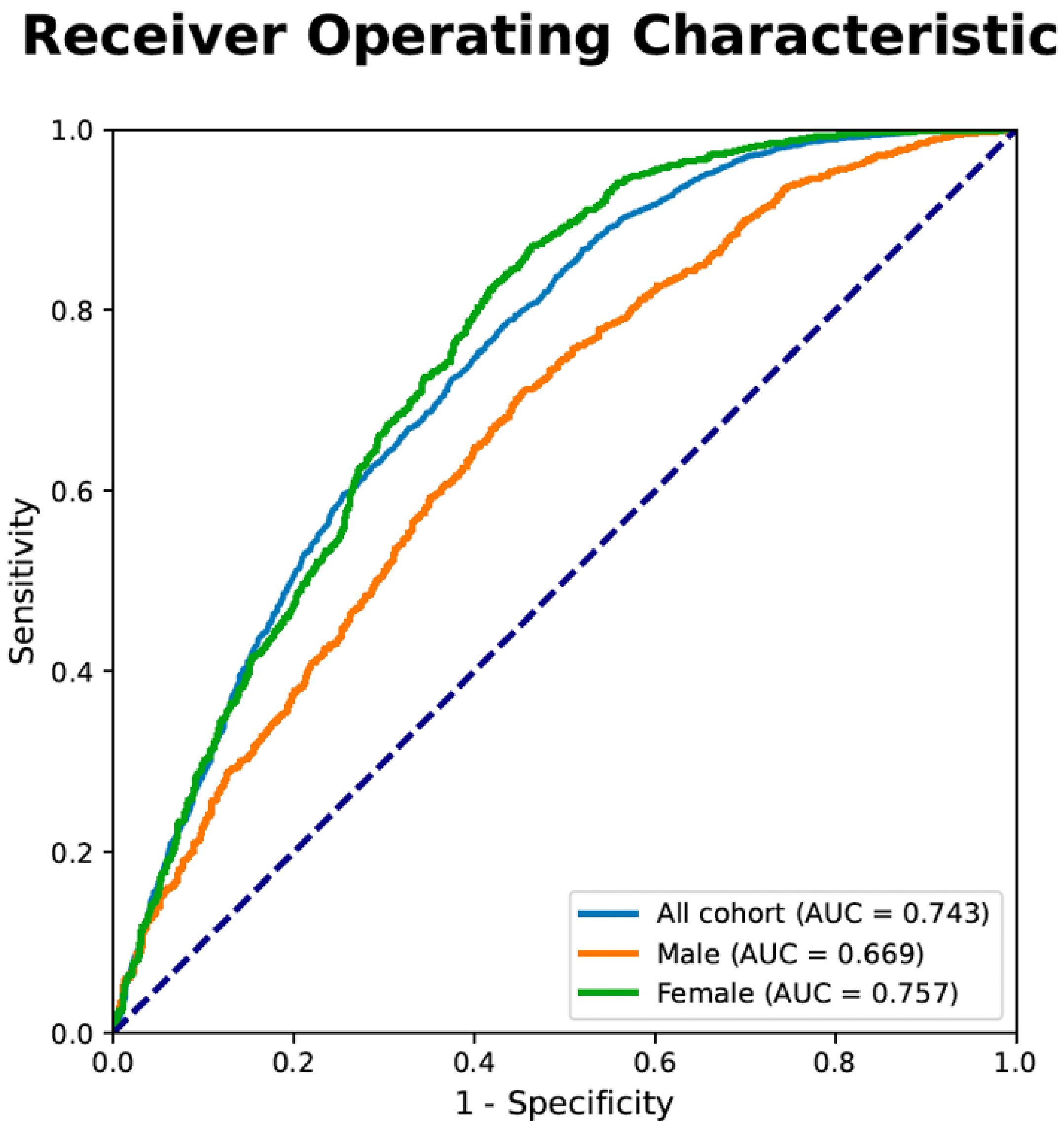
Somers et al: *JCI*, 1995



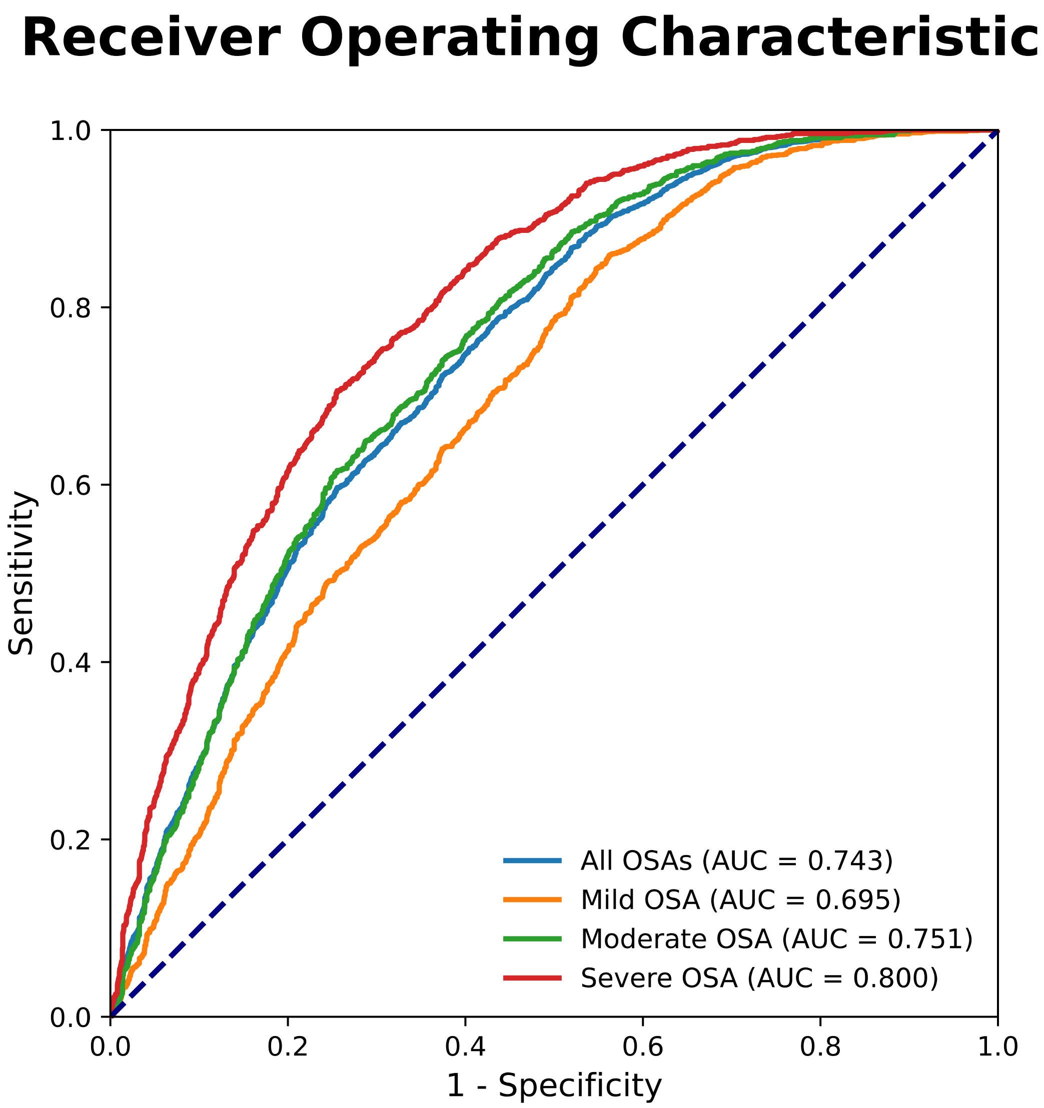
Grimm et al., Am J Cardiol 1996

Prediction of presence of OSA (AHI of >5/hour) based on 12-lead ECG

(**Liu et al, 2023)**



Prediction Accuracy of different severities of OSA based on AHI (Liu et al, 2023)



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Summary

Deep neural networks provide accurate assessments of age, sex, and risks of premature aging disorders, left ventricular dysfunction, HCM, AS, atrial fibrillation and OSA from analysis of the 12-lead standard ECG.

This is an evolving field with enormous implications for patient screening and health care economics.

An A.I.-Generated Picture Won an Art Prize. Artists Aren't Happy.

"I won, and I didn't break any rules," the artwork's creator says.

Jason Allen's AI-generated work, titled "Théâtre D'opéra Spatial," took first place in the digital category at the Colorado State Fair. via Jason Allen