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MAYO CLINIC

Allina Health
MINNEAPOLIS
HEART INSTITUTE

APPLICATION OF ARTIFICIAL INTELLIGENCE TO THE ECG:
FROM RETROSPECTIVE ANALYSIS TO PROSPECTIVE TRIALS AND IMPLEMENTATION

Cardiology Grand Rounds, Minneapolis Heart Institute
Monday, October 21st, 2024

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Funding:
- BEAGLE: Mayo Clinic Kern Center for the Science of Health Care Delivery
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- R01 HL 131535 (coI)
- R01 HS 25402 (coI)
- R01 HL 143070 (coI)

Disclosures:
- Mayo Clinic and PN have a relationship with AliveCor surrounding QTc measurement
- Mayo Clinic, PAN, and other co-investigators have licensed various AI-ECG algorithms and associated technologies to Anumana
- Mayo Clinic and other co-investigators have a relationship with Eko regarding AI-ECG for low EF

Patents:

• 62/751,395	Neural Networks for Atrial Fibrillation Screening
• 17847536.4	Electrocardiogram Analytical Tool
• PCT/US2019/033	Automatic Sensing of Features within an Electrocardiogram
• 16/221,214	Predicting Transient Ischemic Events Using ECG

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WHAT DOES THE FUTURE OF ECG INTERPRETATION LOOK LIKE?

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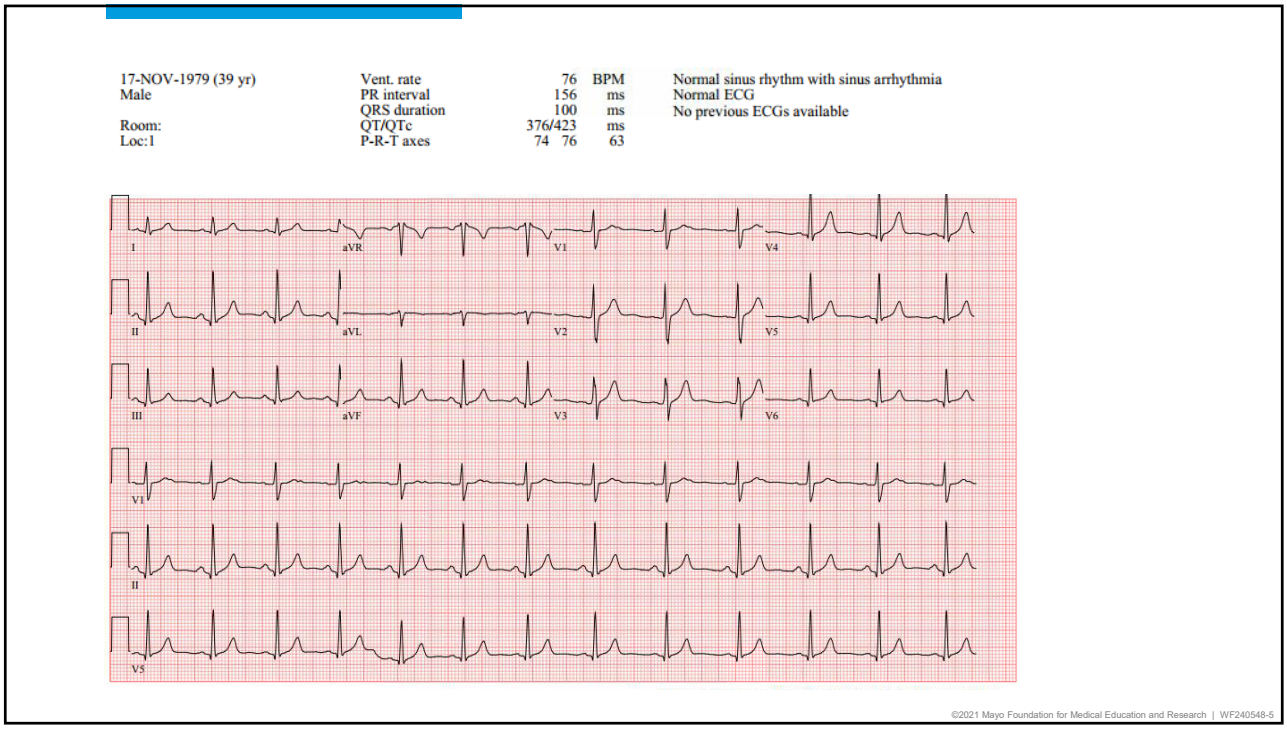
17-NOV-1979 (39 yr)
Male
Room:
Loc:1
Vent. rate 76 BPM
PR interval 156 ms
QRS duration 100 ms
QT/QTc 376/423 ms
P-R-T axes 74 76 63
Normal sinus rhythm with sinus arrhythmia
Normal ECG
No previous ECGs available
I
aVR
V1
V4
II
aVL
V2
V5
III
aVF
V3
V6
V1
II
V5
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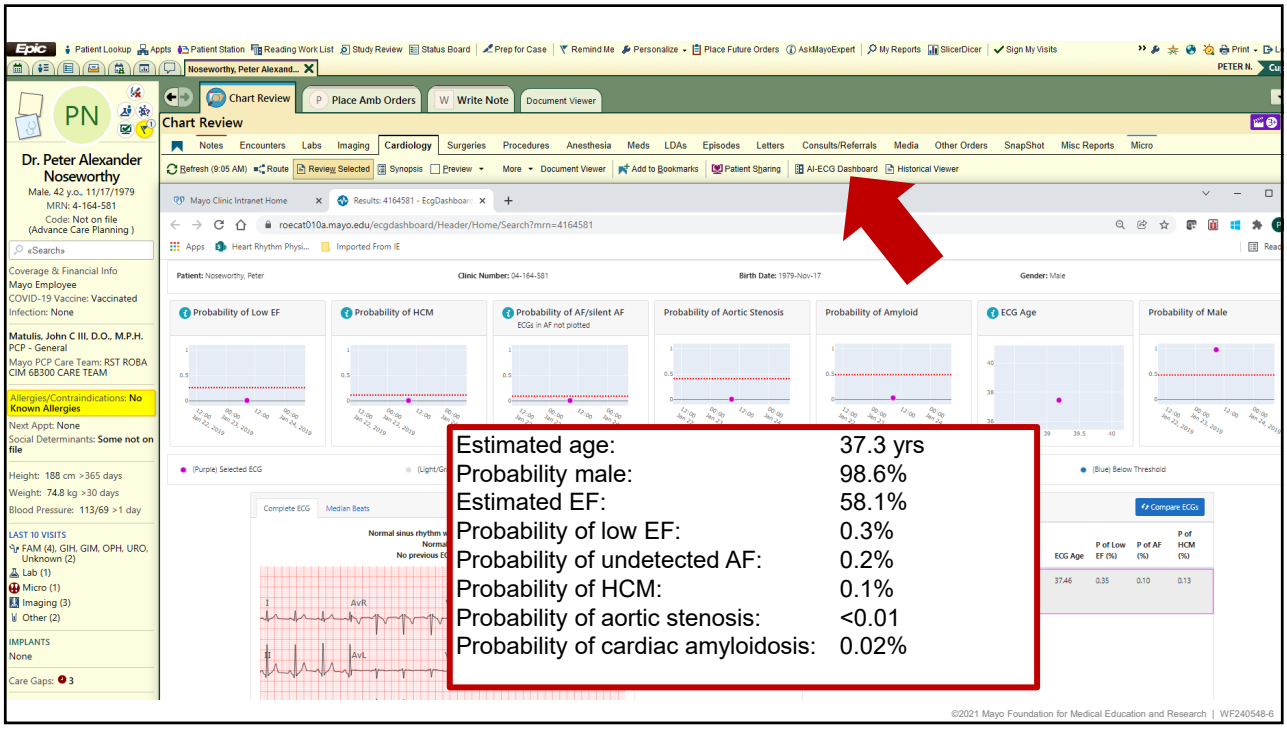
Chart Review
Dr. Peter Alexander Noseworthy
Male, 42 y.o., 11/17/1979
MRN: 4-164-581
Probability of Low EF
Probability of HCM
Probability of AF/silent AF
Probability of Aortic Stenosis
Probability of Amyloid
ECG Age
Probability of Male
Estimated age: 37.3 yrs
Probability male: 98.6%
Estimated EF: 58.1%
Probability of low EF: 0.3%
Probability of undetected AF: 0.2%
Probability of HCM: 0.1%
Probability of aortic stenosis: <0.01
Probability of cardiac amyloidosis: 0.02%
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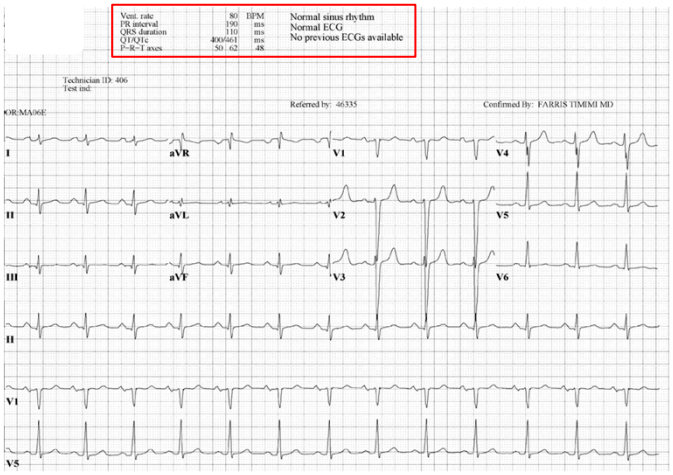
35M PRESENTS AFTER HIS SISTER DIES SUDDENLY



AI ECG predicted a 76% probability of low EF

Echocardiogram EF: 18%

Found to have familial cardiomyopathy

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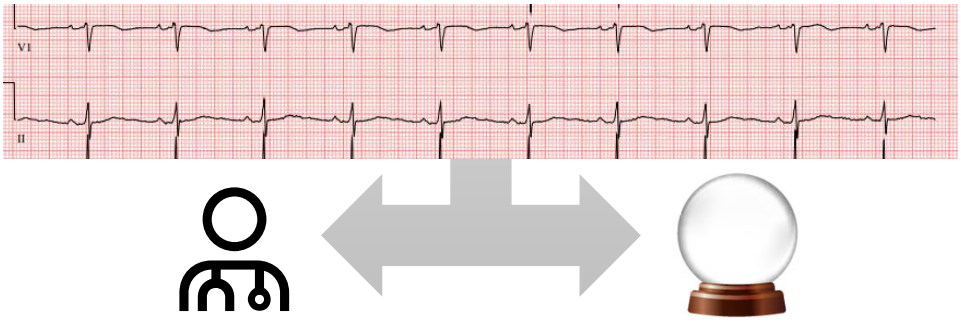
AI-ENHANCED ECG INTERPRETATION



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

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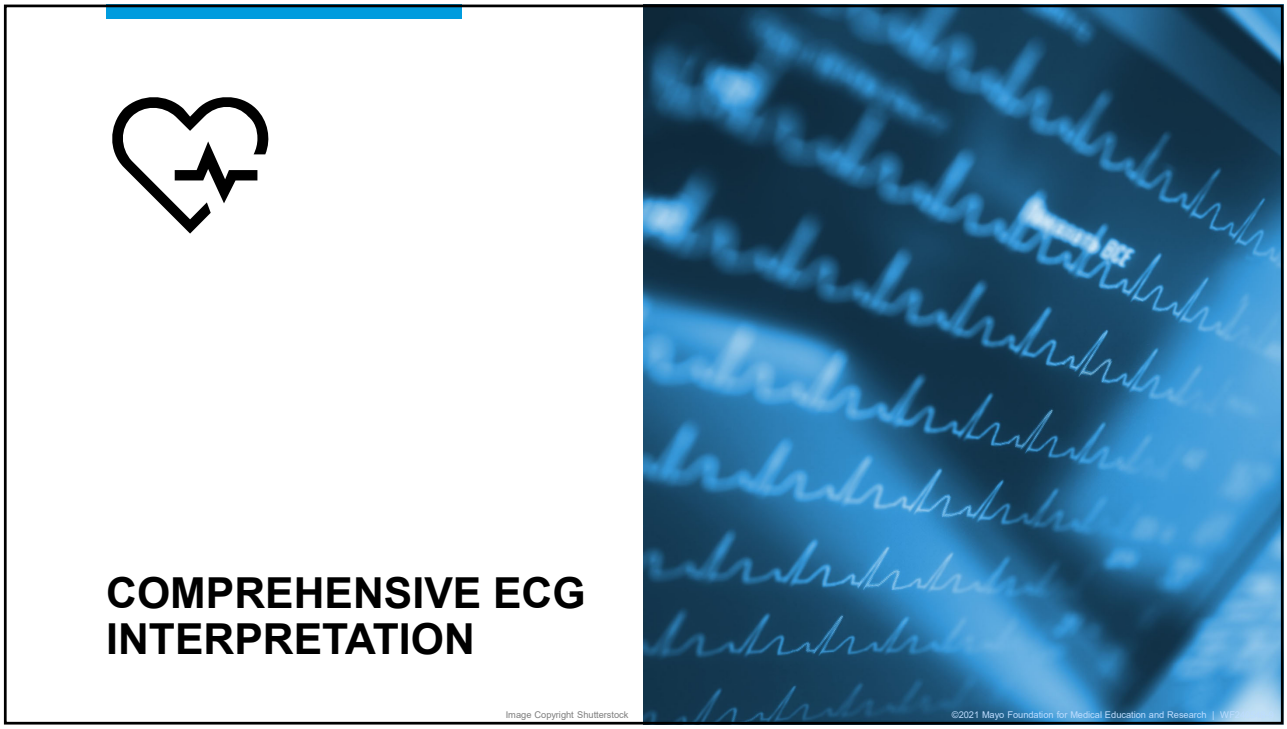

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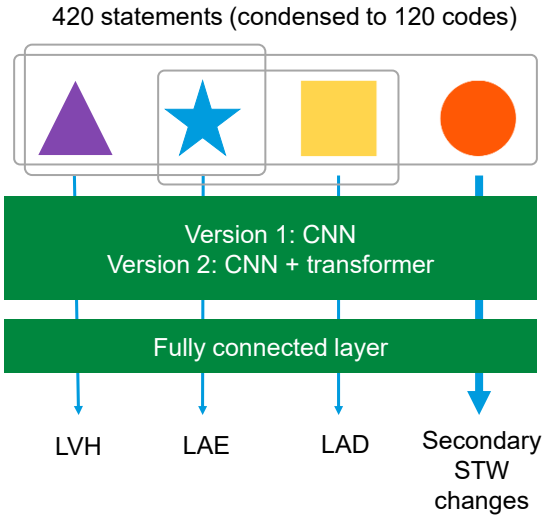
ITERATIVE PROCESS: 8M ECGS, TRAIN/VAL/TEST SETS

1. CNN to predict individual labels
   - Good for each code, but too inclusive
2. Predict codes in combination
   - Learns association between codes
3. Re-weighting important codes
   - Better performance for “can’t miss” codes
4. Avoid time domain loss in convolution
   - Fewer rate errors (brady/tachy confusion



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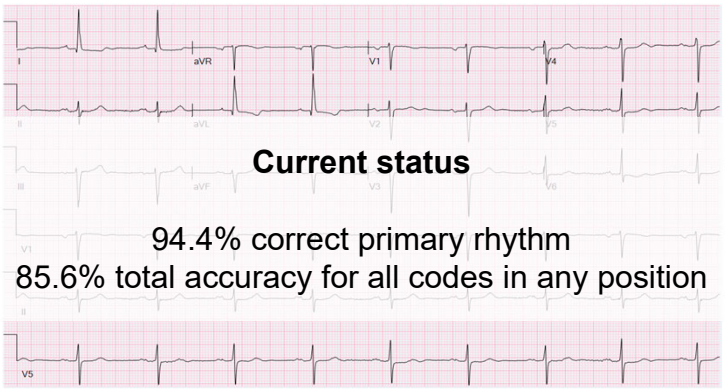
VALIDATION: CAN IT PASS THE ‘TURING TEST’?



Current status

94.4% correct primary rhythm
85.6% total accuracy for all codes in any position

Marquette read	AI read	ECG lab read
Sinus bradycardia with 1° A-V block Left ventricular hypertrophy Repolarization abnormality Abnormal ECG	Sinus bradycardia with 1° A-V block Minimal voltage criteria for left ventricular hypertrophy with secondary repolarization abnormality	Sinus bradycardia with 1° A-V block Left ventricular hypertrophy with secondary repolarization abnormality

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SEEING BEYOND HUMAN INTERPRETATION….

3 EXAMPLES

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LOW EJECTION FRACTION

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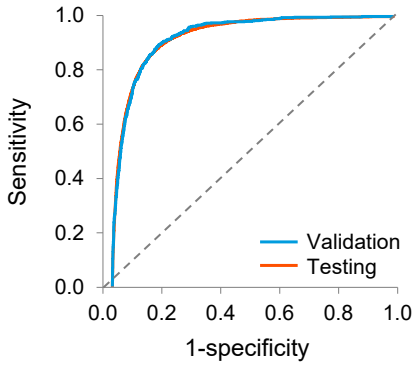
DETECTION OF LOW EJECTION FRACTION



Area under curve of EF

AI ECG = 0.93

Validated
In other populations

Redrawn from: Nat Med 2019
Redrawn from: JACC sup 2020

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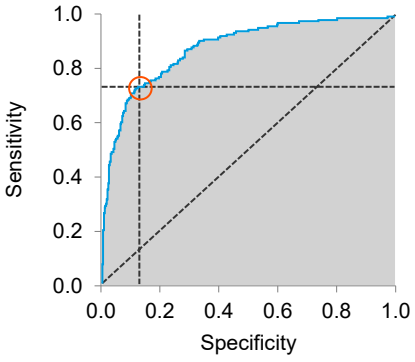
VALIDATION IN OTHER CLINICAL SETTINGS

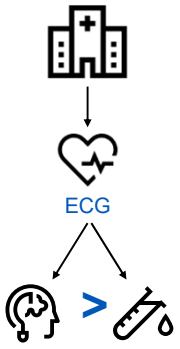
Emergency Department
(Patients Present with Dyspnea)

AUC 0.89



AUC: 0.885 (0.857, 0.913)
Accuracy: 85.9% (84.1%, 87.6%) (1,380/1,606)
Sensitivity: 73.8% (66.4%, 80.3%) (121/164)
Specificity: 87.3% (85.5%, 89.0%) (1,259/1,442)
Positive Predictive Value: 39.8% (34.3%, 45.5%) 121/304)
Negative Predictive Value: 96.7% (95.6%, 97.6%) (1,259/1,302)
Odds Ratio: 19.4 (13.2, 28.3)
F1 Score: 51.7

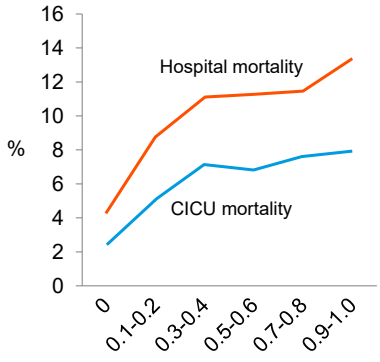
Dyspnea in the ED



AI outperforms standard of care
For prediction of LV Dysfunction

Cardiac Critical Care Unit

AUC 0.83



AI-ECG predicted probability of LVSD
(rounded to nearest 0.1)

Redrawn from: Circ AI 2020
Redrawn from: EHJ ACC 2020

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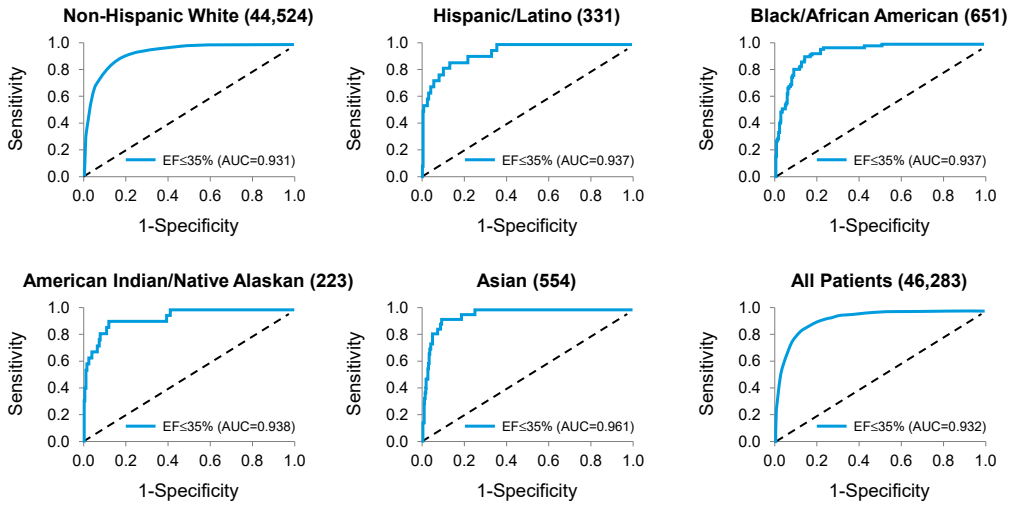
CONSISTENT MODEL PERFORMANCE ACROSS RACIAL GROUPS



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BRIEF DETOUR….

….CAN WE IMPROVE THE MODEL FURTHER?

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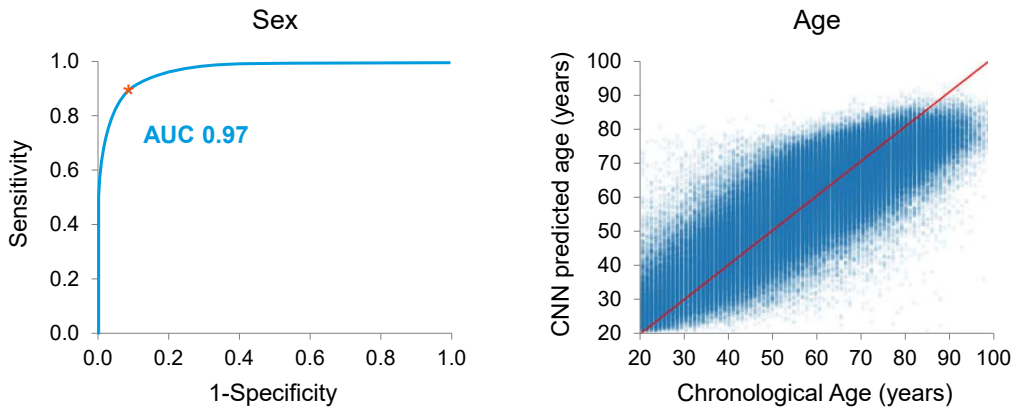
DOES ADJUSTING FOR AGE OR SEX IMPROVE THE LOW EF MODEL?… NO!



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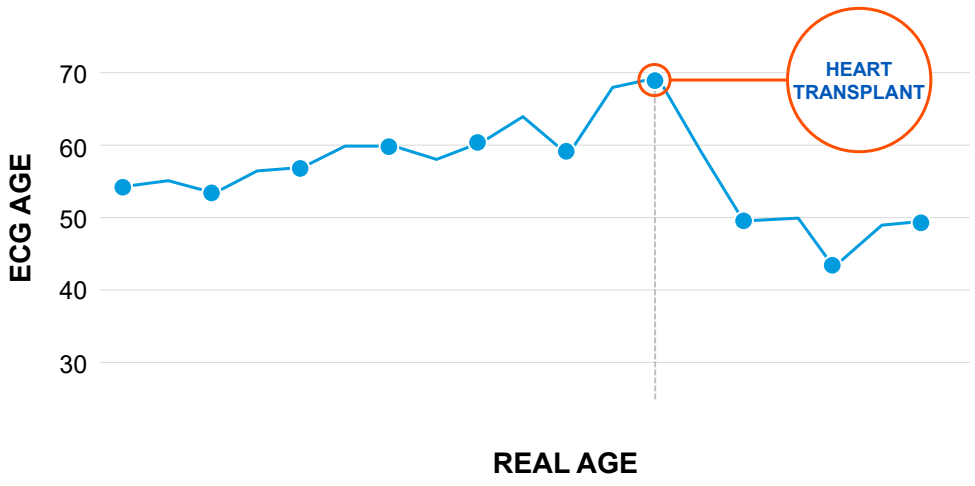
PROGRESSION OF ECG AGE OVER TIME….



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TRANSLATION TO PRACTICE

…“delivering the potential of AI will require testing interventions in RCTs and reporting these results in a standardized and transparent fashion,” *Nature Medicine* Editorial Board

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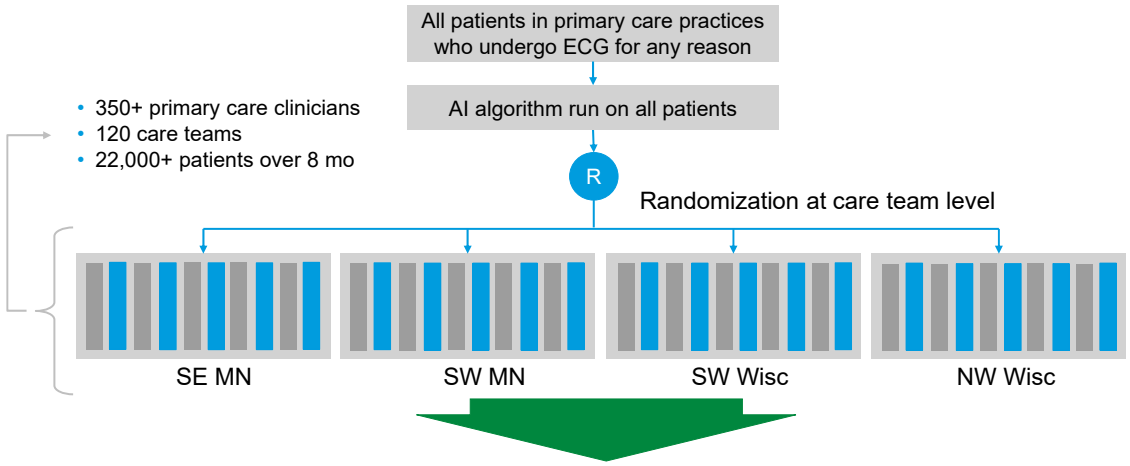
EAGLE: CLUSTER-RANDOMIZED, PRAGMATIC DESIGN



Outcomes: 1. New low EF diagnosis, 2. Treatment patterns, 3. Qualitative assessment

Redrawn from: Clinicaltrials.gov NCT04000087

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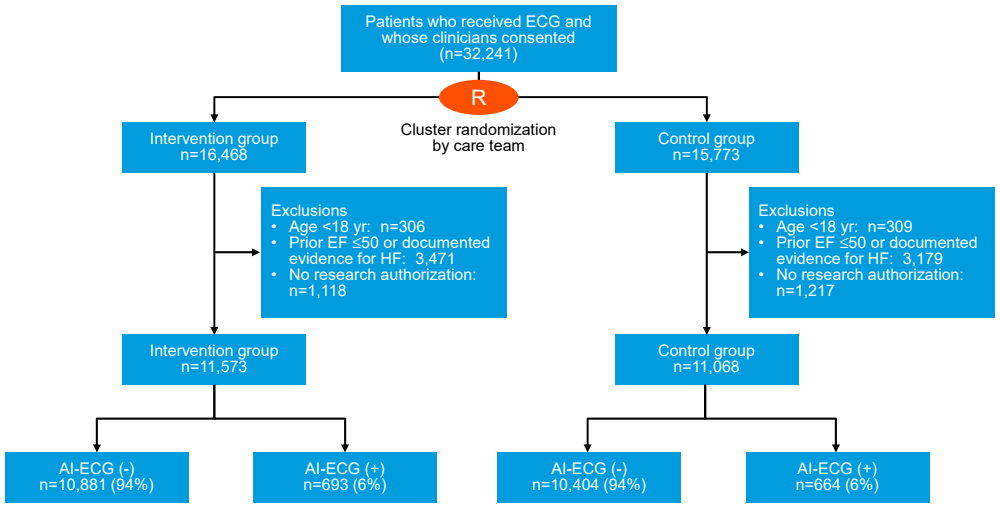
FLOW DIAGRAM/ENROLLMENT



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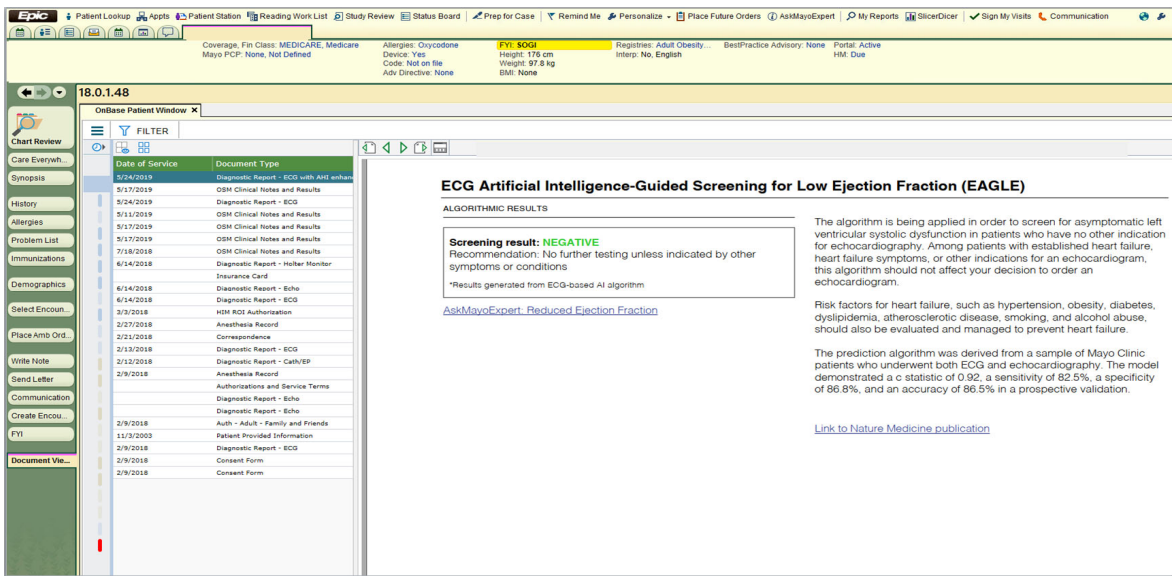

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BASELINE CHARACTERISTICS

Characteristic	Control (n=11,068)	Intervention (n=11,573)
Age, y, mean (SD)	60.5 (17.6)	60.5 (17.5)
18-64	5,934 (53.6%)	6,256 (54.1%)
65-74	2,630 (23.8%)	2,764 (23.9%)
≥75	2,504 (22.6%)	2,553 (22.1%)
Female, N(%)	6,123 (55.3%)	6,080 (52.5%)
Rural, N (%)	5,019 (45.4%)	6,323 (54.6%)
Medical History, N(%)		
Hypertension	6,177 (55.8%)	6,491 (56.1%)
Diabetes	2,221 (20.1%)	2,347 (20.3%)
MI	717 (6.5%)	770 (6.7%)
PAD	444 (4.0%)	411 (3.6%)
Stroke or TIA	381 (3.4%)	409 (3.5%)
Prior AF	919 (8.3%)	991 (8.6%)
New AF on Index ECG	248 (2.2%)	246 (2.1%)
Valvular Heart Disease	152 (1.4%)	129 (1.1%)
CKD	1,209 (10.9%)	1,373 (11.9%)
Prior Echocardiogram	1,896 (17.1%)	1,903 (16.4%)
Location of ECG ordered		
Outpatient Clinic	5,969 (53.9%)	6,043 (52.2%)
Emergency Room	4,056 (36.6%)	4,411 (38.1%)
Hospital	1,043 (9.4%)	1,119 (9.7%)

Redrawn from: Nature Med 2021

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ECGS WERE ORDERED FOR A VARIETY OF INDICATIONS

Indication for ECG	N (%)
Chest pain	3,014 (13.3%)
Baseline screening	2,467 (10.9%)
Pre-operative study	1,510 (6.7%)
Shortness of breath/dyspnea	840 (3.7%)
Dizziness	328 (1.4%)
Other Diagnosis	2,789 (12.3%)
Unknown	11,693 (51.6%)

Redrawn from: Nature Med 2021

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PRIMARY FINDINGS

- The intervention **increased the diagnosis of low EF** (1.6% vs. 2.1%, odds ratio 1.32, p=0.007)
- Echo order was at clinicians' discretion
- More echocardiograms for patients with + AI-ECG (38.1% control vs. 49.6% intervention, P<0.001)
- But, overall echocardiogram utilization was similar (18.2% vs. 19.2%, P=0.17)

Nature Med 2021

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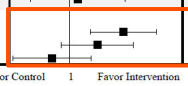
SUBGROUP ANALYSES

Subgroup	Control			Intervention			Odds Ratio (95% CI)	P for interaction
	No. of patients	No. of events	% events	No. of patients	No. of events	% events		
Overall	11068	178	1.6%	11573	244	2.1%	1.32 (1.08 , 1.61)	
Age								0.66
18-64 yr	5934	64	1.1%	6256	82	1.3%	1.22 (0.88 , 1.69)	
65-74 yr	2630	50	1.9%	2764	66	2.4%	1.26 (0.87 , 1.84)	
≥75 yr	2504	64	2.6%	2553	96	3.8%	1.49 (1.08 , 2.05)	
Sex								0.11
Female	6123	49	0.8%	6080	79	1.3%	1.63 (1.14 , 2.33)	
Male	4945	129	2.6%	5493	165	3.0%	1.16 (0.92 , 1.46)	
Rural								0.89
No	6048	89	1.5%	5249	98	1.9%	1.27 (0.95 , 1.70)	
Yes	5019	89	1.8%	6323	146	2.3%	1.31 (1.00 , 1.71)	
Hypertension								0.22
No	4891	62	1.3%	5082	71	1.4%	1.10 (0.78 , 1.55)	
Yes	6177	116	1.9%	6491	173	2.7%	1.43 (1.12 , 1.84)	
Diabetes								0.88
No	8847	127	1.4%	9226	172	1.9%	1.30 (1.04 , 1.64)	
Yes	2221	51	2.3%	2347	72	3.1%	1.34 (0.92 , 1.96)	
AF								0.49
No	9901	128	1.3%	10336	168	1.6%	1.25 (0.98 , 1.60)	
Prior AF	919	23	2.5%	991	43	4.3%	1.77 (1.06 , 2.96)	
New AF on index ECG	248	27	10.9%	246	33	13.4%	1.24 (0.68 , 2.23)	
MI or PAD								0.49
No	9985	124	1.2%	10484	180	1.7%	1.37 (1.05 , 1.79)	
Yes	1083	54	5.0%	1089	64	5.9%	1.19 (0.82 , 1.73)	
CKD								0.96
No	9859	143	1.5%	10200	193	1.9%	1.31 (1.05 , 1.63)	
Yes	1209	35	2.9%	1373	51	3.7%	1.29 (0.84 , 2.00)	
Prior echo								0.38
No	9172	144	1.6%	9670	207	2.1%	1.36 (1.08 , 1.71)	
Yes	1896	34	1.8%	1903	37	1.9%	1.09 (0.68 , 1.74)	
ECG Location								0.02
Outpatient Clinic	5969	57	1.0%	6043	98	1.6%	1.71 (1.23 , 2.37)	
Emergency Department	4056	66	1.6%	4411	96	2.2%	1.32 (0.92 , 1.88)	
Hospital	1043	55	5.3%	1119	50	4.5%	0.84 (0.57 , 1.24)	



Nature Med 2021 (in press)

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TREATMENT FOR LOW EF

	Control (n=70)	Intervention (n=102)	P
New Prescription, N (%)			
ACEi/ARB or Beta Blockers	52 (74.3%)	74 (72.5%)	0.800
ACEi/ARB	37 (52.9%)	44 (43.1%)	0.210
ACEi	27 (38.6%)	39 (38.2%)	0.964
ARB	14 (20.0%)	7 (6.9%)	0.010
Beta Blockers	38 (54.3%)	65 (63.7%)	0.215
Baseline or New Prescription, N(%)			
ACEi/ARB or Beta Blockers	65 (92.9%)	99 (97.1%)	0.199
ACEi/ARB	53 (75.7%)	83 (81.4%)	0.370
ACEi	44 (62.9%)	68 (66.7%)	0.607
ARB	19 (27.1%)	26 (25.5%)	0.809
Beta Blockers	62 (88.6%)	95 (93.1%)	0.297

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OTHER INCIDENTAL ECHO FINDINGS

	Negative ECG (n=3,643)	"False Positive" ECG (n=365)
All other findings	315 (8.6%)	56 (15.3%)
Valve Heart Disease (≥moderate)	287 (7.9%)	55 (15.1%)
Aortic Regurgitation	44 (1.2%)	8 (2.2%)
Mitral Regurgitation	60 (1.6%)	12 (3.3%)
Tricuspid Regurgitation	123 (3.4%)	27 (7.4%)
Aortic Stenosis	85 (2.3%)	16 (4.4%)
Mitral Stenosis	3 (0.1%)	0 (0.0%)
Bicuspid Aortic Valve	15 (0.4%)	2 (0.5%)
Atrial Septal Defect	18 (0.5%)	0 (0.0%)
Ventricular Septal Defect	11 (0.3%)	0 (0.0%)
Hypertrophic Cardiomyopathy	3 (0.1%)	1 (0.3%)

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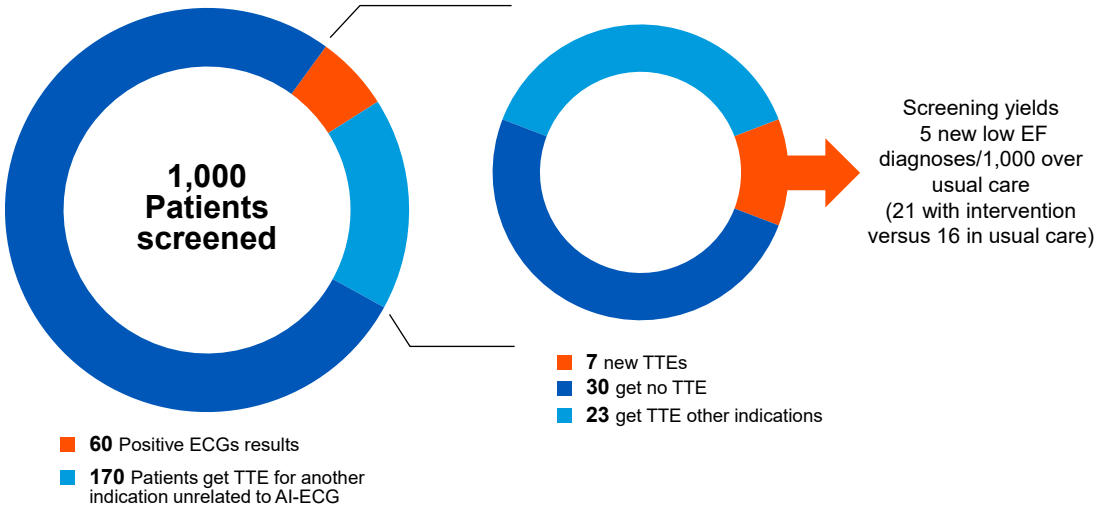
OVERALL DIAGNOSTIC YIELD



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HYPERTROPHIC CARDIOMYOPATHY

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HYPERTROPHIC CARDIOMYOPATHY

Matching

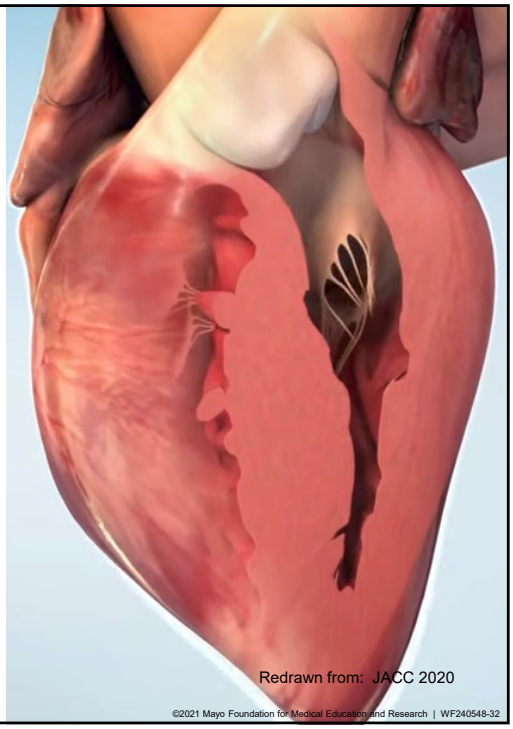
Age and sex match

HCM (n=3,060)

Controls (n=63,941)

Model dev (70:10:20)

Training	Validation	Testing
(n=46,901)	(n=6,700)	(n=13,400)
HCM (n=2,142)	HCM (n=306)	HCM (n=612)
Controls (n=44,759	Controls (n=6,394)	Controls (n=12,788)



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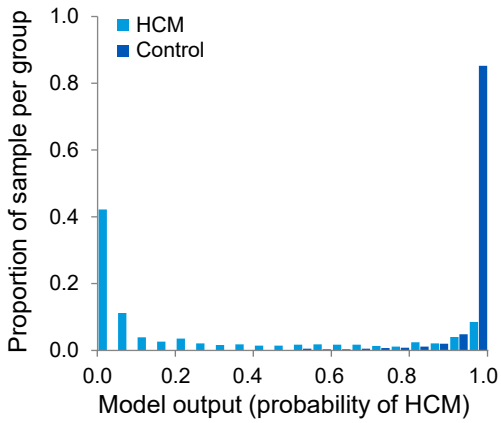
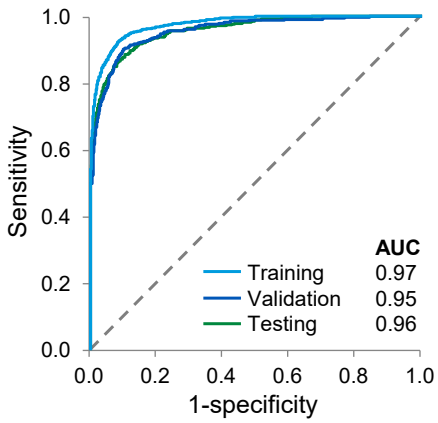
HCM: MODEL PERFORMANCE





Redrawn from: JACC 2020

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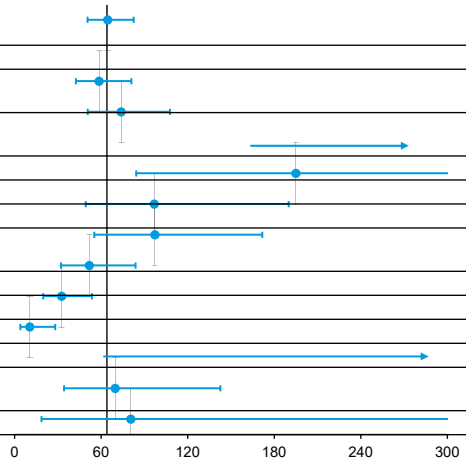
HCM: SUBGROUP PERFORMANCE

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)



Results in genotyped patients?

- With sarcomeric mutation (n=286): 97% (IQR 80-99%), 3.5% false neg
- Without sarcometic mutation (n=574): 96% (IQR 70-99%), 8% false neg

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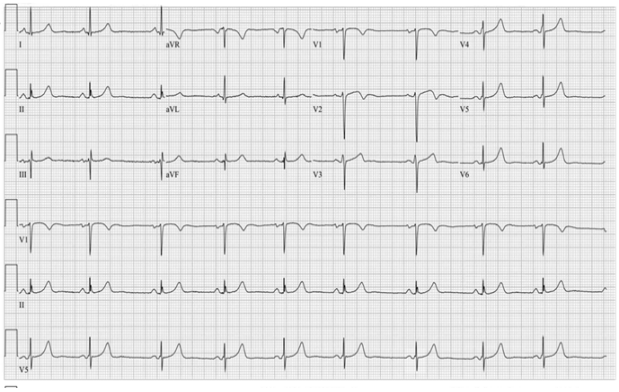
CLINICAL CASE: 25-YEAR-OLD WOMAN WITH HCM



72.6% probability of HCM!

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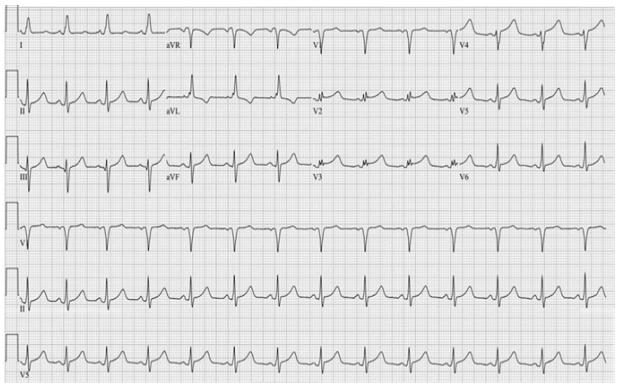
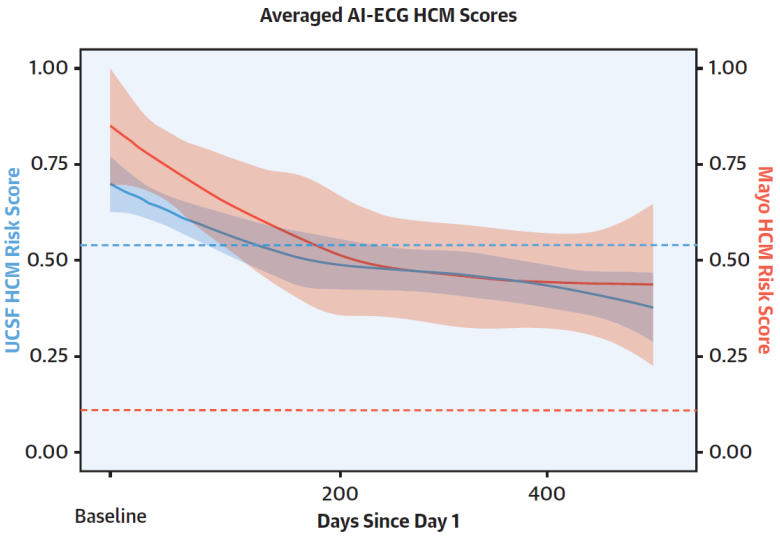
POST-OP: PATIENT UNDERGOES SEPTAL MYECTOMY



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

36

HCM: ASSESSING TREATMENT RESPONSE TO MAVACAMTEN



JACC 2022

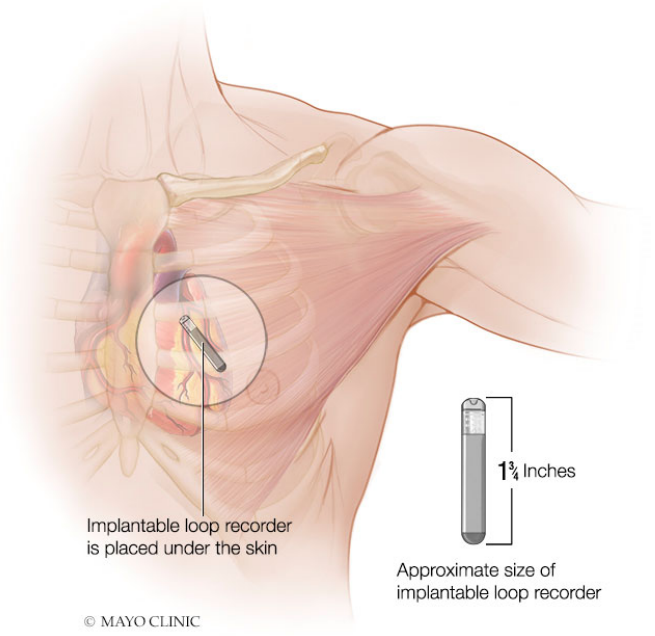
37

3

ATRIAL FIBRILLATION

38

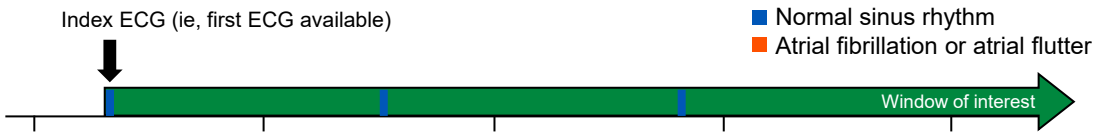
CURRENT MEANS FOR AF DETECTION



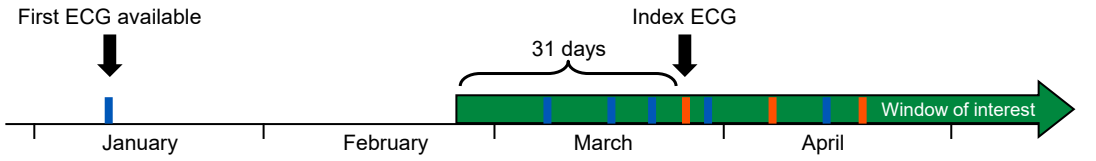
39

ATRIAL FIBRILLATION RISK

Patient with no atrial fibrillation rhythms recorded



Patient with at least one atrial fibrillation rhythm recorded



Redrawn from: Lancet, 2019

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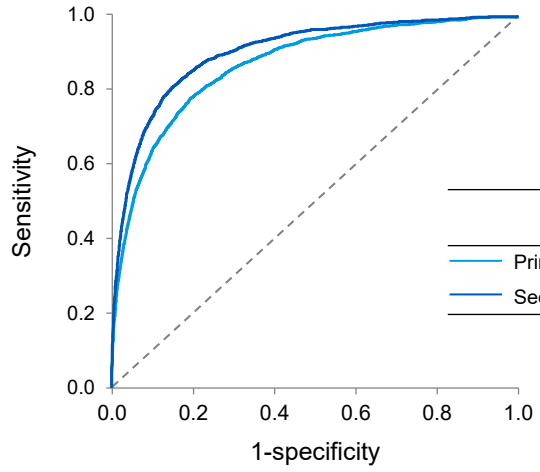
ATRIAL FIBRILLATION RISK

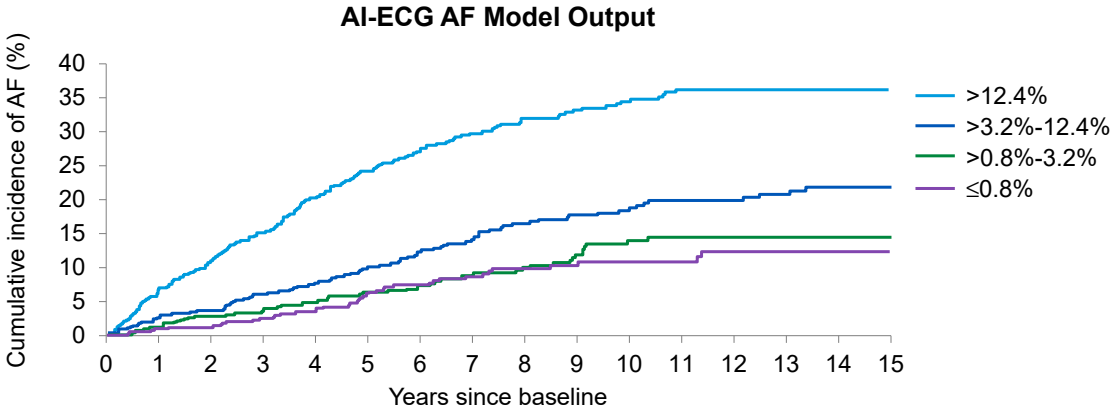


	AUC	Sensitivity (%)	Specificity (%)	95% CI
Primary	0.87	79.0	79.5	0.86-0.88
Secondary	0.90	82.3	83.4	0.90-0.91

Redrawn from: Lancet 2019

41

CAN AI-ECG PREDICT INCIDENT AF? MAYO CLINIC STUDY OF AGING

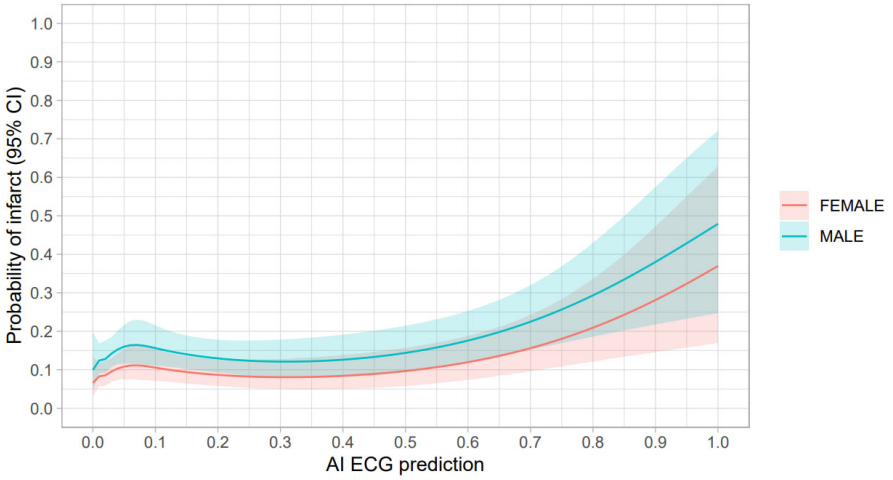


NB: A threshold of 0.5 translated to a cumulative incidence of AF about 25% at 2 years and 50% at 10 years

Redrawn from: Circ AE, 2020

42

CAN AI-ECG PREDICT INFARCTS? MAYO CLINIC STUDY OF AGING



Under review

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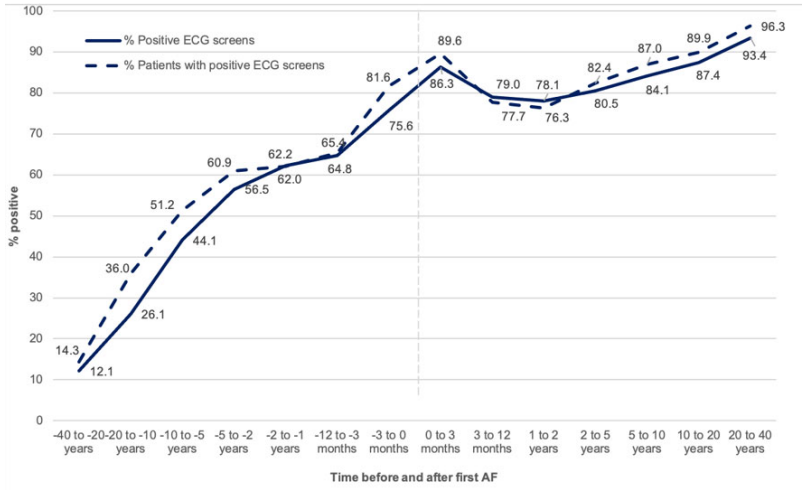
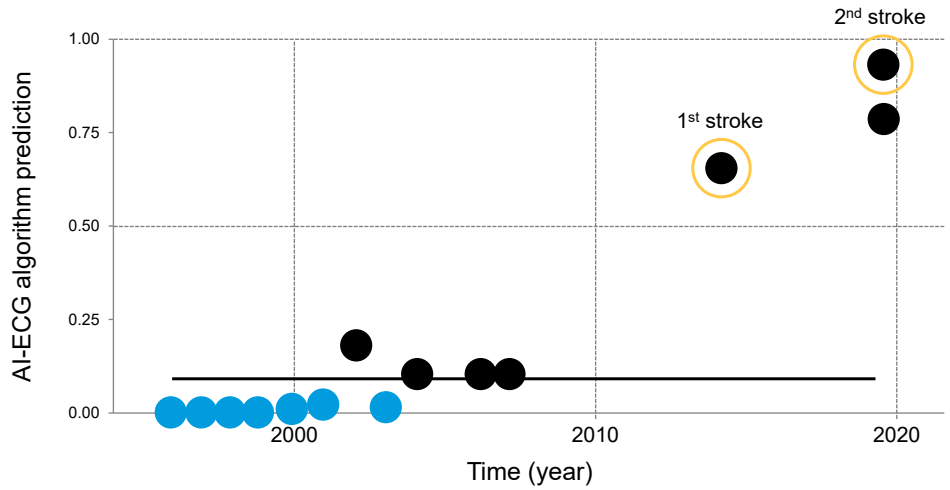
HOW DOES THE MODEL OUTPUT CHANGE OVER TIME?



Under review

44

CASE: COULD AI HAVE PREVENTED A STROKE?



Redrawn from: HRCR 2019

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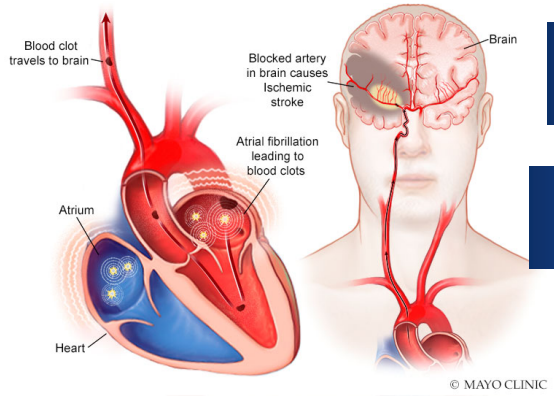
STROKE MECHANISM
TREATMENT IMPLICATIONS



LAA independent (atherosclerosis of the arch, carotid, intracerebral vessels) → Aspirin

LAA dependent (Atrial Fibrillation) → Anticoagulant

Treatment depends on whether atrial fibrillation is present – but it is intermittent and hard to detect

46

….CAN THE AF ALGORITHM DRIVE PROSPECTIVE SCREENING EFFORTS?

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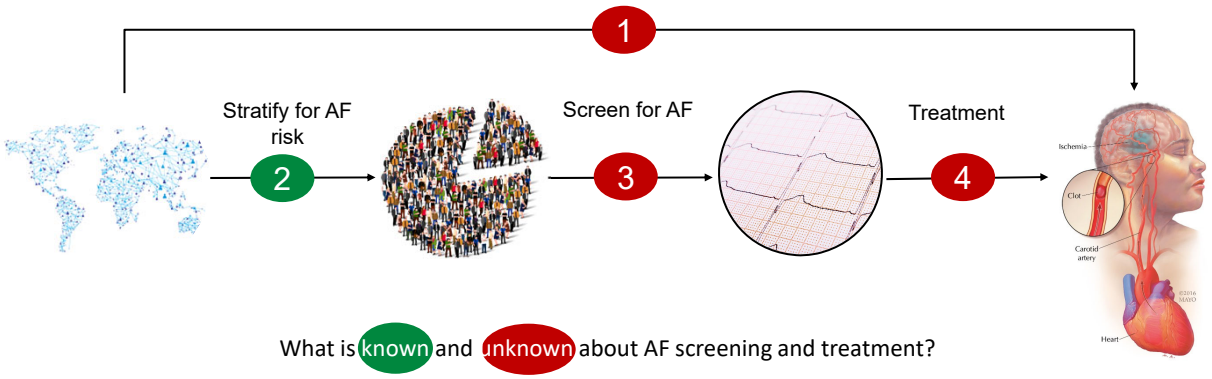

What is known and unknown about AF screening and treatment?

1. Overall question: does screening, monitoring, and treatment eventually result in better outcomes?
2. Does AI-ECG screening identify patients at high probability of unrecognized AF?
3. How to best monitor for AF in at risk patients?
4. Do we anticoagulate patients or not?

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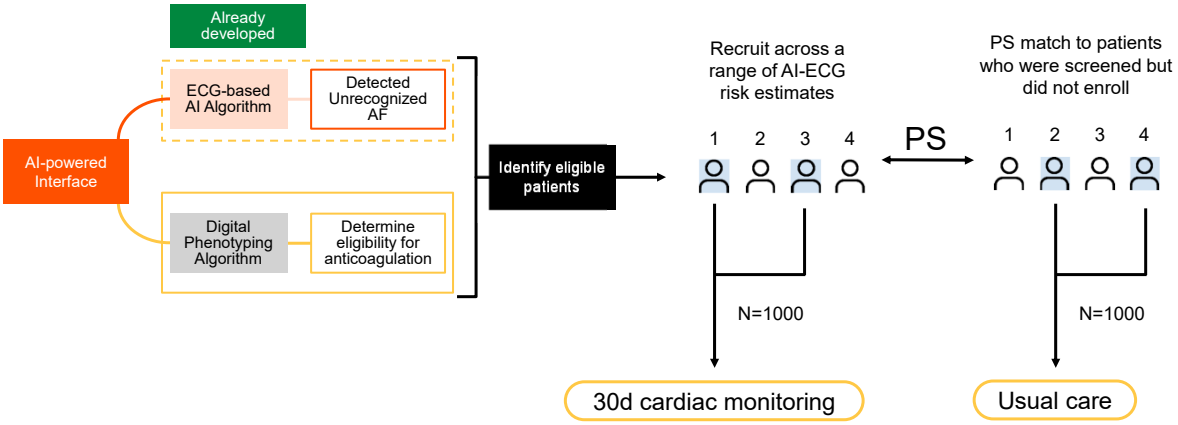
PILOT STUDY: EHR INTEGRATION FOR MOBILE/SITE-LESS PRAGMATIC RCT

BATCH ENROLLMENT FOR AN ARTIFICIAL INTELLIGENCE-GUIDED INTERVENTION TO LOWER NEUROLOGIC EVENTS IN PATIENTS WITH UNDIAGNOSED ATRIAL FIBRILLATION (BEAGLE) (NCT04208971)



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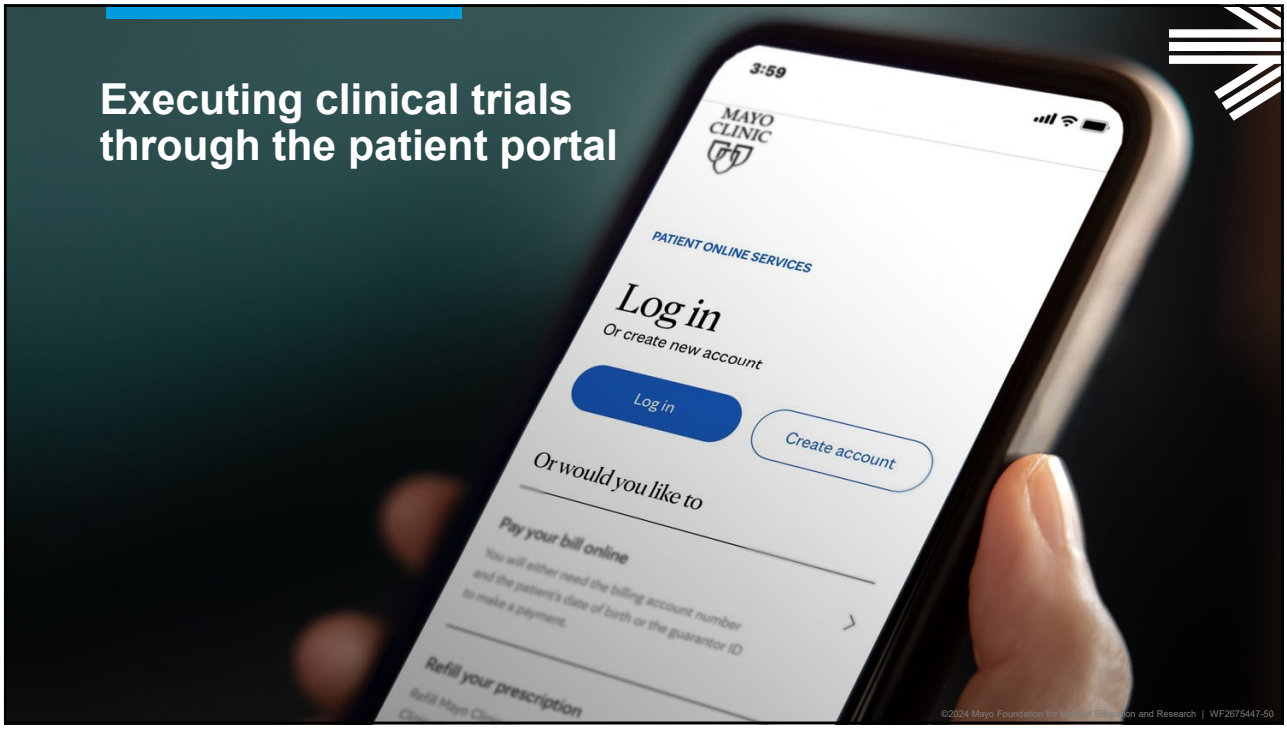
Executing clinical trials through the patient portal



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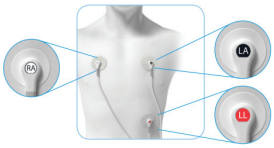
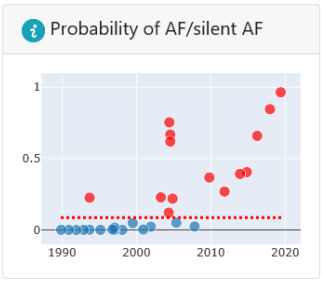
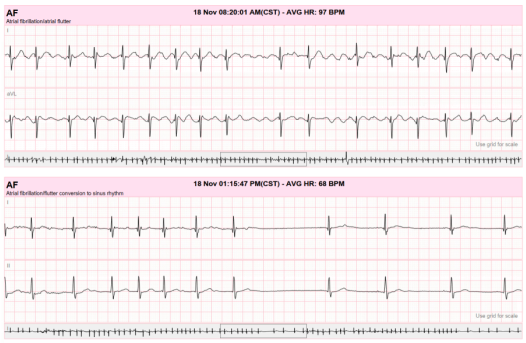
PARADIGM: EHR-INTEGRATION FOR MOBILE/SITE-LESS PRAGMATIC RCT

BATCH ENROLLMENT FOR AN ARTIFICIAL INTELLIGENCE-GUIDED INTERVENTION TO LOWER NEUROLOGIC EVENTS IN PATIENTS WITH UNDIAGNOSED ATRIAL FIBRILLATION (BEAGLE) (NCT04208971)



CASE EXAMPLE:
- Retired MD with diabetes, HTN, and chronic kidney disease
- 30 NSR ECGs at Mayo Clinic





51

"I would have never known that I had A-fib," said Maercklein, a 73-year-old retired hospital finance executive at Mayo who lives in rural Olmsted County, Minn. "For me, it worked out incredibly well. Without this study, who knows when I would have been diagnosed."

HEALTH TECH

AI caught a hidden problem in one patient's heart. Can it work for others?

By Casey Ross April 26, 2021 Reprints

Peter Maercklein poses for a portrait near his home in rural Olmsted County, Minn. An artificial intelligence-enabled tool developed by Mayo Clinic picked up on his atrial fibrillation.
JOSEPH AHLQUIST FOR STAT

Somewhere in Peter Maercklein's heartbeat was an abnormality no one could find. He survived a stroke 15 years ago, but doctors never saw anything alarming on follow-up electrocardiograms. Then, one day last fall, an artificial intelligence algorithm read his EKGs and spotted something else: a ripple in the calm that indicated an elevated risk of atrial fibrillation.

Redrawn from: STAT April 26th, 2021

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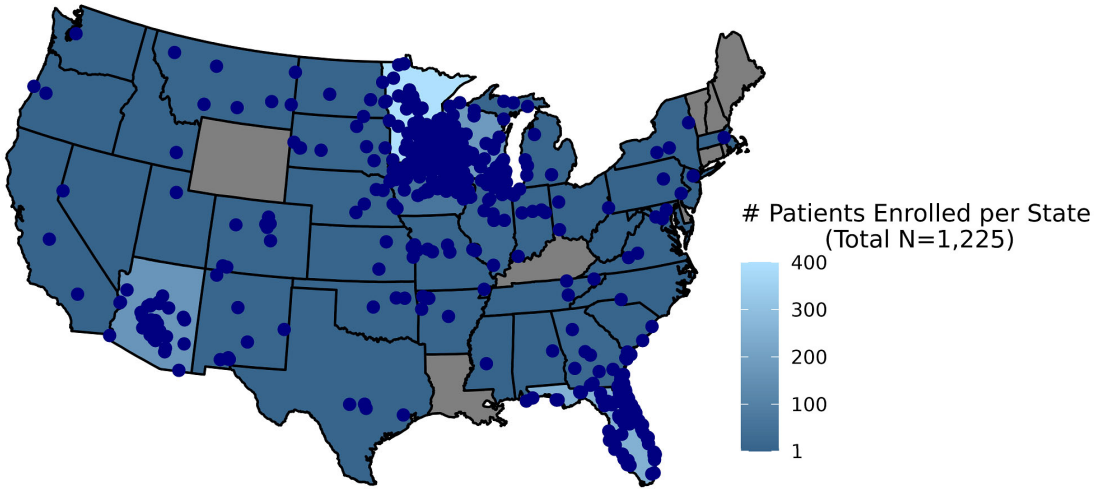
ENROLLMENT FROM 40 STATES



Lancet 2022

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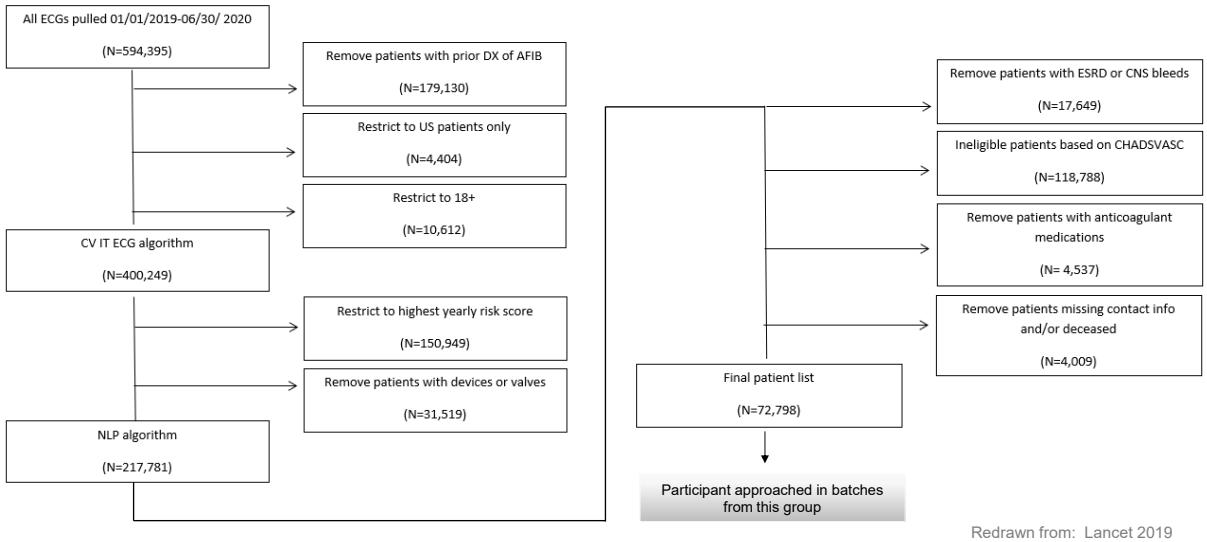
ENROLLMENT FLOW DIAGRAM



Redrawn from: Lancet 2019

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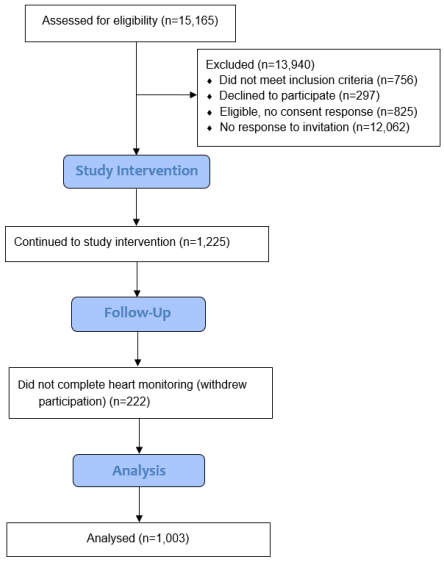
ENROLLMENT FLOW DIAGRAM



Lancet 2022

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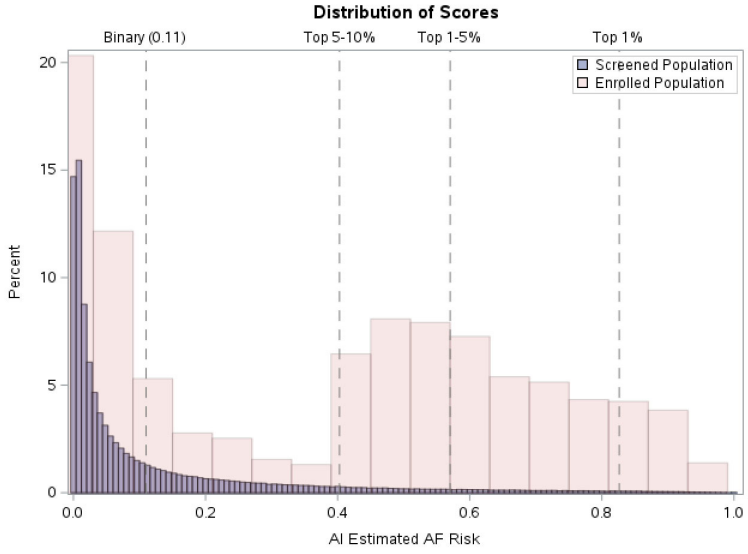
DISTRIBUTION OF SCORES:
SCREENED AND ENROLLED POPULATIONS



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DEMOGRAPHICS

	Low AI risk (n=370)	High AI risk (n=633)	Total (n=1003)
Age, years			
Mean	71·9 (10·3)	75·2 (7·6)	74·0 (8·8)
Median	73 (67–79)	76 (71–81)	75 (69–80)
Gender			
Men	201 (54·3%)	419 (66·2%)	620 (61·8%)
Women	169 (45·7%)	214 (33·8%)	383 (38·2%)
Race			
White	353 (95·4%)	612 (96·7%)	965 (96·2%)
Black	7 (1·9%)	8 (1·3%)	15 (1·5%)
Asian	0	7 (1·1%)	7 (0·7%)
Other	6 (1·6%)	4 (0·6%)	10 (1·0%)
Unknown or choose not to disclose	4 (1·1%)	2 (0·3%)	6 (0·6%)
Medical history			
Diabetes	112 (30·3%)	195 (30·8%)	307 (30·6%)
CAD or PAD	112 (30·3%)	269 (42·5%)	381 (38·0%)
Heart failure	34 (9·2%)	142 (22·4%)	176 (17·5%)
Hypertension	295 (79·7%)	531 (83·9%)	826 (82·4%)
Ischaemic stroke, systemic embolism, or TIA	60 (16·2%)	73 (11·5%)	133 (13·3%)
CHA_2DS_2-VASc score	3·4 (1·2)	3·7 (1·3)	3·6 (1·2)

Data are mean (SD) or n (%). CAD=coronary artery disease. AI=artificial intelligence. PAD=peripheral artery disease. TIA=transient ischaemic attack.

Table 1: Characteristics of the trial population at baseline

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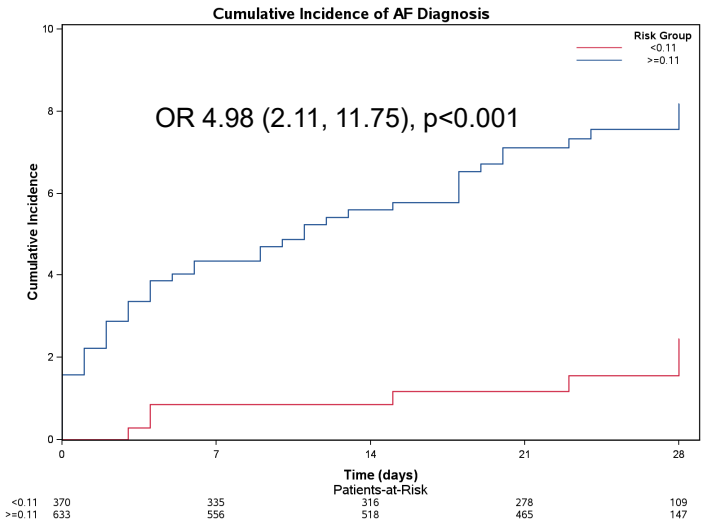
CUMULATIVE AF INCIDENCE (>30SEC):



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PRIMARY AND SECONDARY OUTCOMES

	Low risk (n=370)	High risk (n=633)	Odds ratio (95% CI)	p value
Atrial fibrillation ≥30 s	6 (1·6%)	48 (7·6%)	4·98 (2·11–11·75)	0·0002
Atrial fibrillation ≥6 min	6 (1·6%)	40 (6·3%)	4·09 (1·72–9·75)	0·0015
Atrial fibrillation ≥24 h	1 (0·3%)	10 (1·6%)	5·92 (0·76–46·45)	0·091
Atrial fibrillation burden, %*	4·97 (6·78)	20·32 (37·78)	..	0·016
Longest episode of atrial fibrillation within 24 h, hours*	10·03 (8·57)	8·03 (9·45)	..	0·61
Time to atrial fibrillation diagnosis, days*	13·96 (8·20)	15·36 (10·26)	..	0·71

Data are n (%) or mean (SD), unless specified otherwise. *These outcomes were measured among patients who were diagnosed with atrial fibrillation.

Table 2: **Primary outcome and key secondary clinical outcomes**

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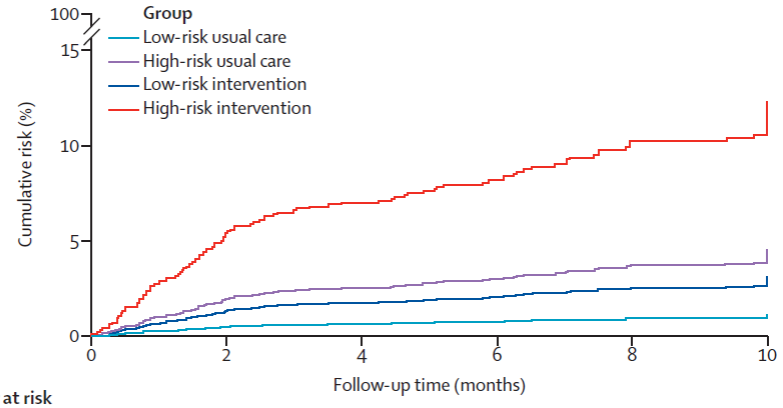
CUMULATIVE INCIDENCE OF ATRIAL FIBRILLATION DIAGNOSIS IN PROPENSITY-SCORE MATCHED TRIAL PARTICIPANTS AND REAL-WORLD CONTROLS



Number at risk						
Low-risk usual care	342	341	338	236	149	90
High-risk usual care	661	648	638	570	412	382
Low-risk intervention	371	365	364	253	145	99
High-risk intervention	632	593	577	514	399	375

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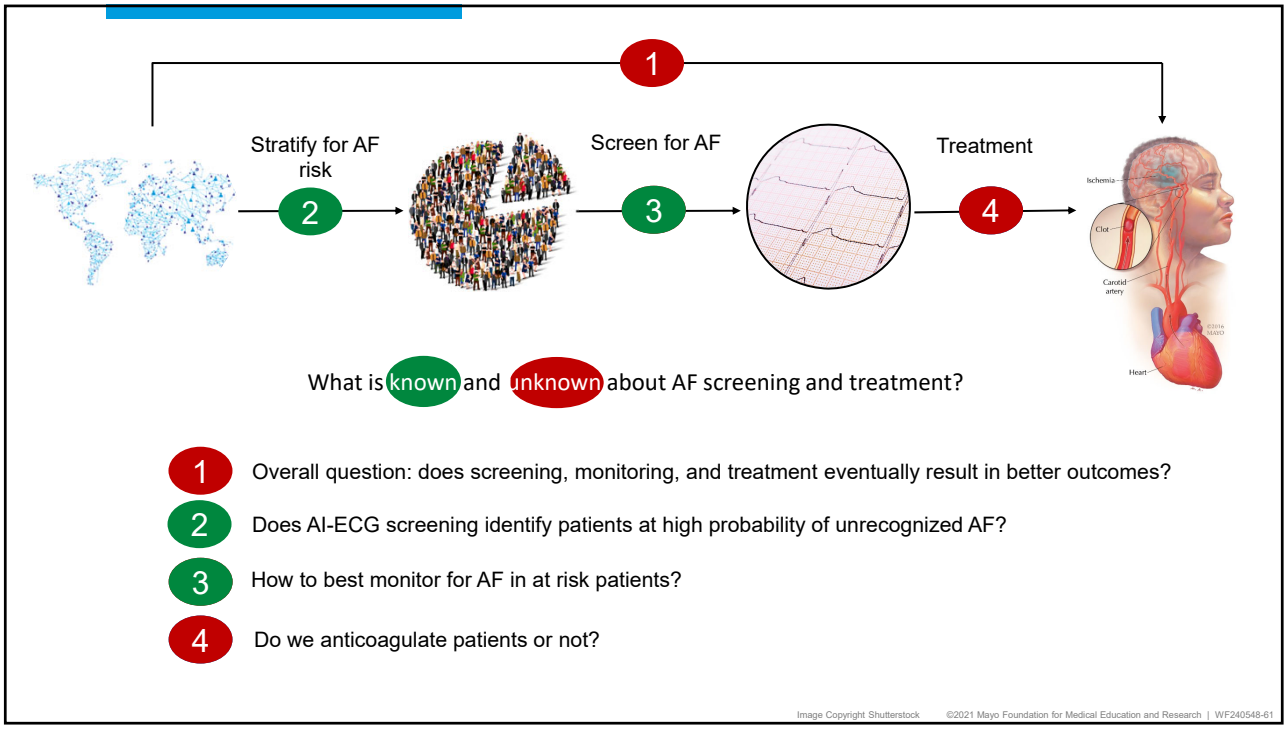

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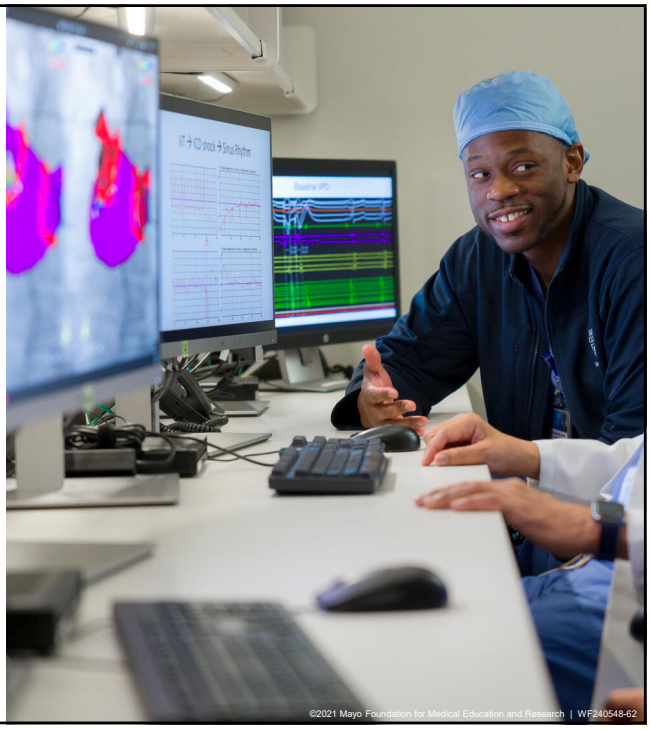
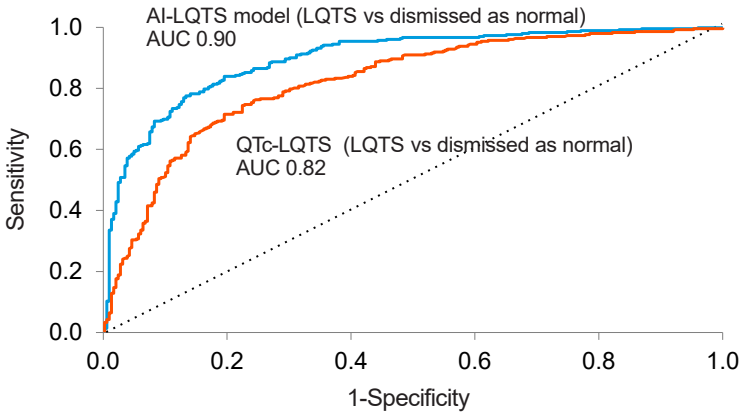
OTHER ARRHYTHMOGENIC CONDITIONS



62

DETECTION OF LQTS

CONVOLUTIONAL NEURAL NETWORK TO DISTINGUISH PATIENTS WITH LQTS FROM THOSE WHO WERE EVALUATED FOR LQTS BUT DISCHARGED WITHOUT THIS DIAGNOSIS



QTc-LQTS vs Normal		
	Estimated negative	Estimated positive
true negative	213	61
true positive	80	233

AI-LQTS vs Normal		
	Estimated negative	Estimated positive
true negative	221	53
true positive	50	263

Redrawn from: Martijn Bos et al: JAMA Cardiol. 2021;6(5):532-538

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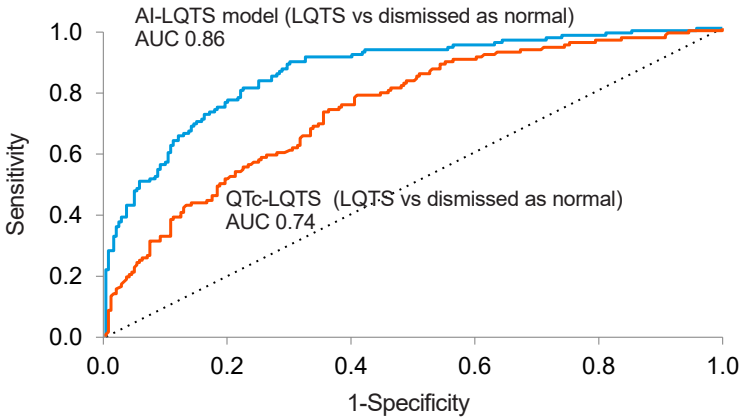
DETECTION OF CONCEALED LQTS

CONVOLUTIONAL NEURAL NETWORK TO DISTINGUISH PATIENTS WITH LQTS FROM THOSE WHO WERE EVALUATED FOR LQTS BUT DISCHARGED WITHOUT THIS DIAGNOSIS



QTc-LQTS vs Normal		
	Estimated negative	Estimated positive
true negative	254	84
true positive	35	94

AI-LQTS vs Normal		
	Estimated negative	Estimated positive
true negative	185	53
true positive	25	104

Redrawn from: Martijn Bos et al: JAMA Cardiol. 2021;6(5):532-538

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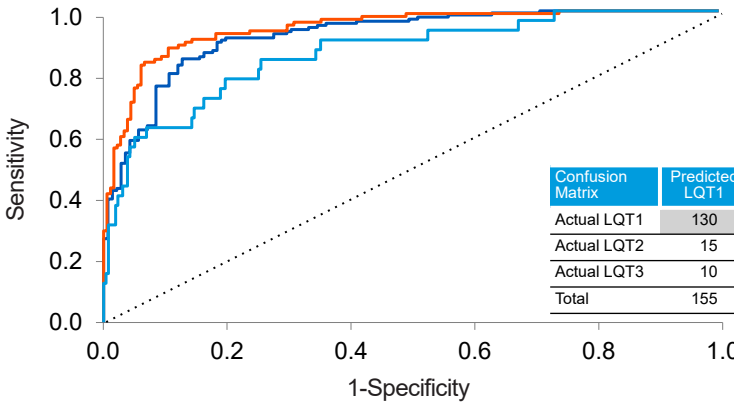
DETECTION OF LQTS SUBTYPES



Confusion Matrix	Predicted LQT1	Predicted LQT2	Predicted LQT3	Total	Accuracy (%)
Actual LQT1	130	10	9	149	87.2
Actual LQT2	15	92	2	109	84.4
Actual LQT3	10	6	16	32	50.0
Total	155	108	27	264	

Redrawn from: Martijn Bos et al: JAMA Cardiol. 2021;6(5):532-538

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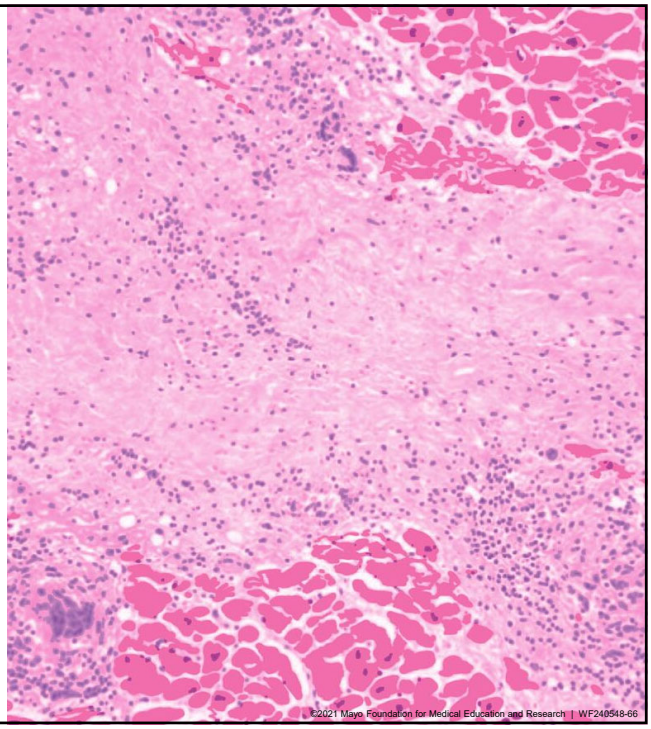
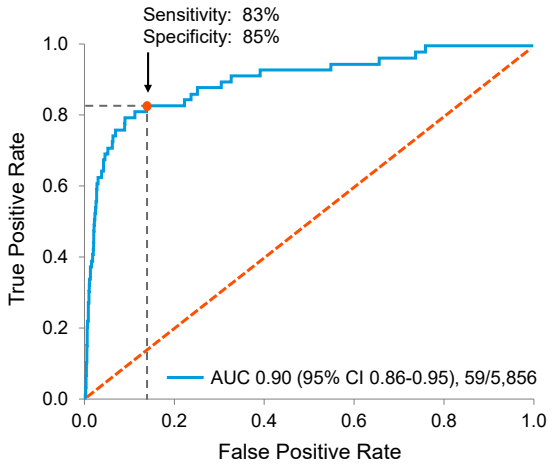
CARDIAC SARCOIDOSIS



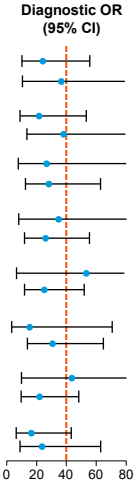
66

A



B

Variables	Sensitivity	Specificity	AUC	Diagnostic OR (95% CI)	P-Value
Sex					
Male	0.81 (30/37)	0.85 (3,040/3,580)	0.89		0.58
Female	0.86 (19/22)	0.85 (1,889/2.217)	0.91		
Age (years)					
<60	0.81 (25/31)	0.84 (2,840/3,386)	0.88		0.41
≥60	0.86 (24/28)	0.87 (2,089/2,412)	0.93		
Hypertension					
Yes	0.81 (13/16)	0.86 (1,866/2,170)	0.92		0.95
No	0.84 (36/43)	0.84 (3,063/3,627)	0.90		
Diabetes					
Yes	0.87 (14/16)	0.83 (894/1,076)	0.95		0.73
No	0.81 (35/43)	0.85 (4,035/4,721)	0.89		
CAD					
Yes	0.89 (8/9)	0.87 (935/1,076)	0.95		0.50
No	0.82 (41/50)	0.85 (3,994/4,721)	0.89		
History of syncope					
Yes	0.82 (9/11)	0.77 (401/521)	0.88		0.42
No	0.83 (40/48)	0.86 (4,528/5,276)	0.91		
CKD					
Yes	0.90 (19/21)	0.82 (556/678)	0.95		0.41
No	0.79 (30.38)	0.85 (4,373/5,119)	0.87		
Conduction abnormalities[b]					
Yes	0.86 (30/35)	0.73 (340/465)	0.89		0.60
No	0.79 (19/24)	0.87 (4,589/5,332)	0.86		



In press

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PVC MEDIATED CARDIOMYOPATHY

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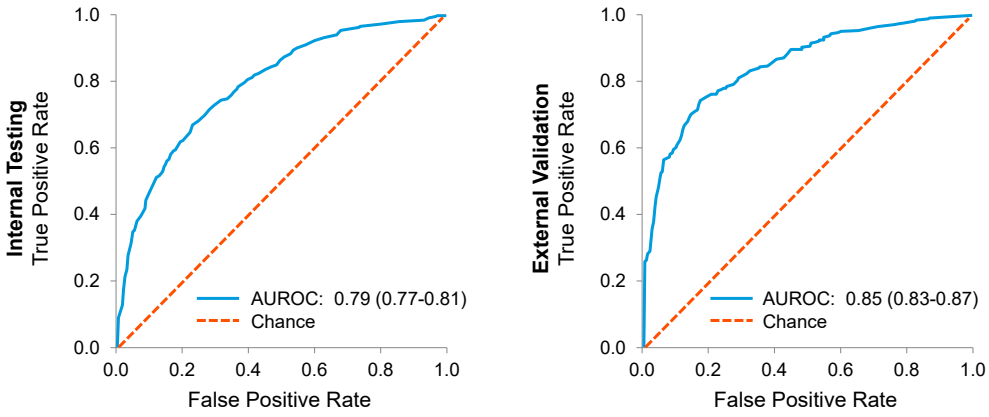
PVC MEDIATED CARDIOMYOPATHY



Redrawn from: In press

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AI-ECG FOR ARVC DETECTION

Case

77 ARVC pts

51% Male, 49% Female

47.2±19.9 years

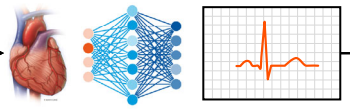
56 PKP2
7 DSG2
6 DSC2
6 DSP
2 JUP

Control

7,043 pts

49% Male, 51% Female

37.3±17.6 years



Training

61 Case ECGs

5,009 Control ECGs

Validation

7 Case ECGs

678 Control ECGs

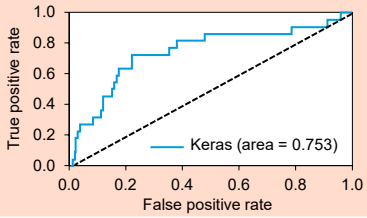
Testing

22 Case ECGs

1,256 Control ECGs

Rhythm AUC 0.75
Median Beat AUC 0.76
Sensitivity 77.3
Specificity 62.9
PPV 3.32
NPV 99.4

Test ROC Curve



Redrawn from: In press

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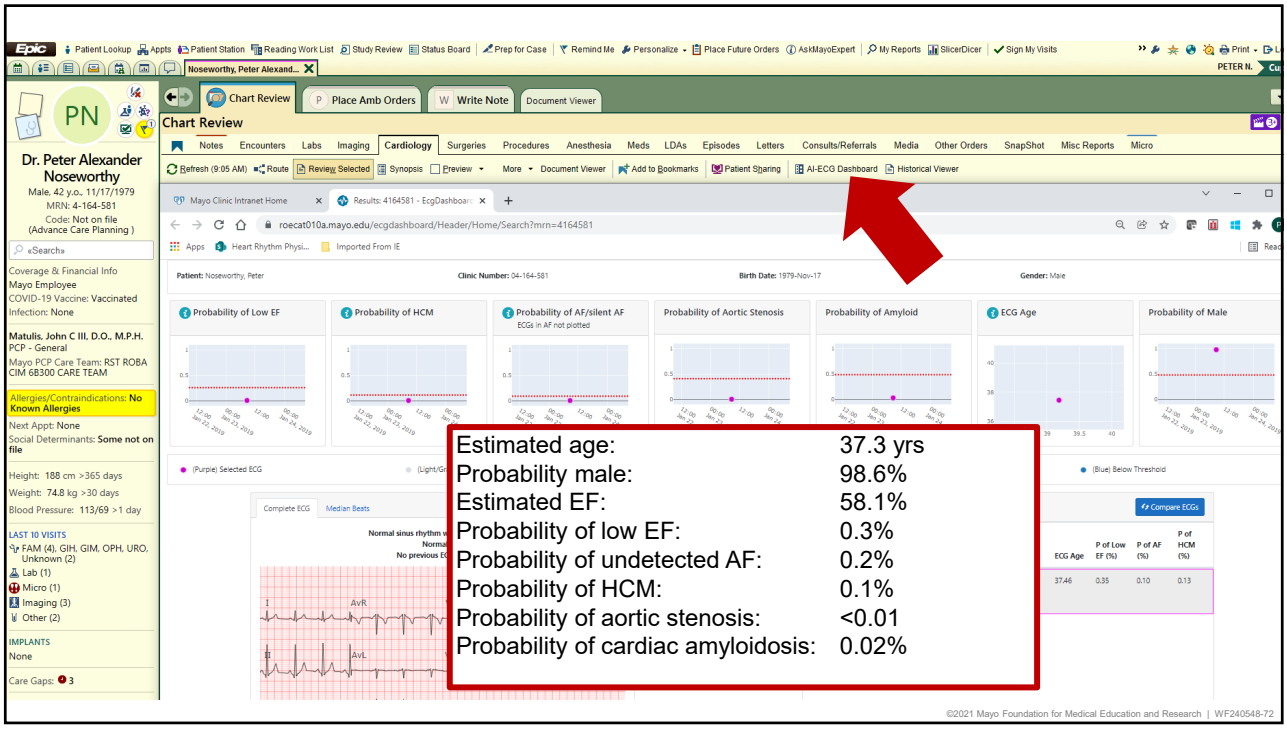
TRANSLATION TO PRACTICE

GETTING RESULTS TO PATIENTS AND CLINICIANS

71



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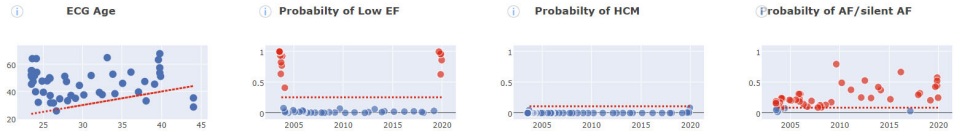
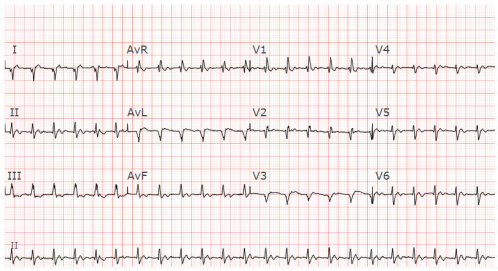
ANOTHER CASE…..



Complete ECG | Median Beats

*** Suspect arm lead reversal interpretation assumes no reversal
Supraventricular tachycardia Incomplete right bundle branch block Possible
Right ventricular hypertrophy Anterolateral infarct ([delete text and date] T wave abnormality, consider inferior ischemia Abnormal ECG



Results

Compare ECGs | Print Report | Download Results

ECG Date	Main Rhythm	Heart Rate	QT/QTc	Real Age	ECG Age	P of Male (%)	P of Low EF (%)	P of AF (%)	P of HCM (%)
12/13/2019 1:45 PM	Supraventricular tachycardia	140	302/459	39.9	51.1	42.99%	86.01%	24.97%	8.47%
11/07/2019 2:10 PM	Left posterior fascicular block	142	292/449	39.8	53.7	20.46%	96.27%	57.62%	0.03%
11/07/2019 5:43 AM	Sinus tachycardia	106	366/483	39.8	67.9	18.69%	95.79%	44.59%	0.12%
11/05/2019 3:31 PM	Sinus tachycardia	116	332/461	39.8	57.5	62.02%	62.84%	52.21%	1.37%
09/03/2019 3:38 PM	Probable	121	322/457	39.6	63.4	29.47%	99.72%	42.74%	0.81%
03/05/2019 7:47 AM	Sinus tachycardia	112	358/488	39.1	45.4	22.38%	3.48%	20.73%	0.01%
02/07/2018 9:55 AM	Sinus tachycardia	108	336/448	38.0	33.1	60.99%	0.41%	32.23%	0.03%
12/11/2017 9:15 AM	Normal sinus rhythm	93	348/432	37.9	47.3	18.37%	1.81%	29.62%	0.00%
02/20/2017 8:04 AM	Normal sinus rhythm	94	354/442	37.1	39.6	66.81%	2.85%	3.15%	0.00%

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ECG ON A STETHOSCOPE "EXPERT IN YOUR POCKET"

AI Screens for EF | 15 seconds | Study in progress

- ✓ No Murmur Detected
- ✓ Normal Sinus ECG Rhythm
- ✓ Normal EMAT
- ✓ Normal Ejection Fraction

Analysis of ECG

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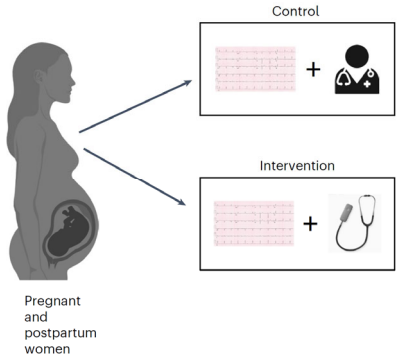
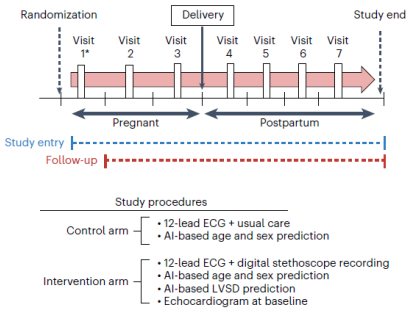
AI-ECG TO DETECT PERI-PARTUM CARDIOMYOPATHY IN NIGERIA





Nigeria has the highest rate of peripartum cardiomyopathy and is associated with mortality in 1/96 deliveries.

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AI-ECG TO DETECT PERI-PARTUM CARDIOMYOPATHY IN NIGERIA

Table 2 | Primary and other prespecified outcomes

Outcome	Intervention (*n*=587)	Control (*n*=608)	Effect estimate (95% CI)	*P* value
Primary outcome				
AI-enabled digital stethoscope	24/587	12/608	2.12 (1.05, 4.27)	0.032

Using the stethoscope, peripartum cardiomyopathy was diagnosed in 4.1% versus 2.0% of patients with usual care

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Enrollment and demographics
125,610
Total ECGs
2,454
Patients
56%
Women, age 53±15
46
States with participants
11
Countries with participants
5 Months
Length of the study
Attia et al. accepted to Nature Medicine

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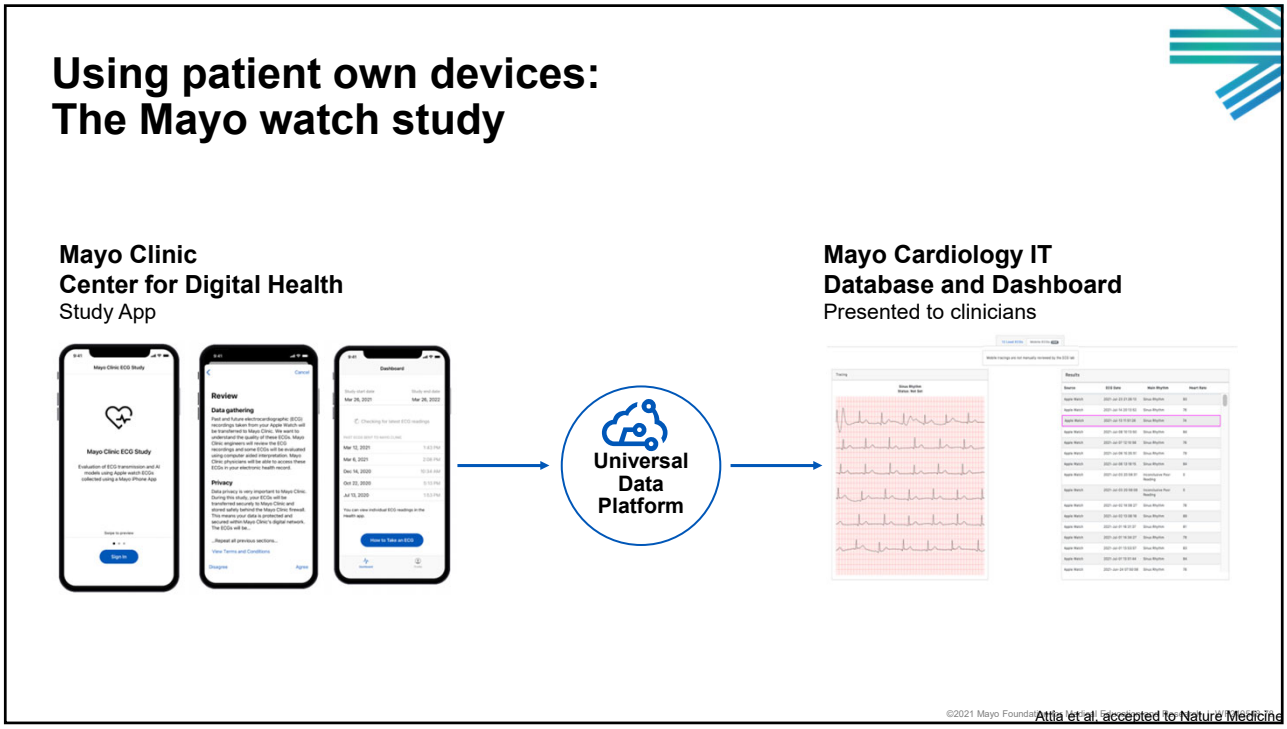
Using patient own devices:
The Mayo watch study
Mayo Clinic
Center for Digital Health
Study App
Universal Data Platform
Mayo Cardiology IT
Database and Dashboard
Presented to clinicians
Attia et al. accepted to Nature Medicine

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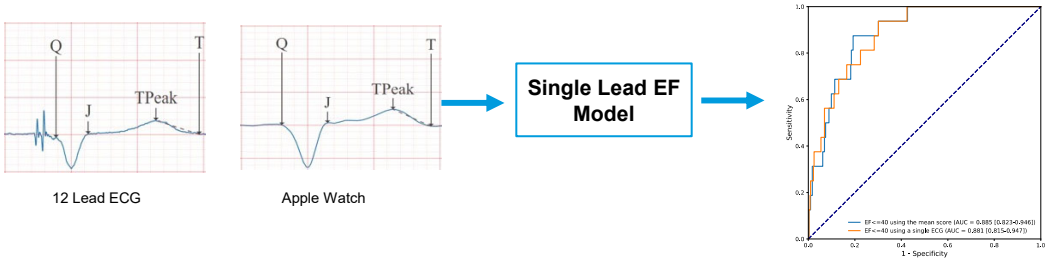
Low EF algorithm applied to the watch data

- Single lead
- Clinical Echocardiograms as gold standard
- Excellent performance for detecting heart failure



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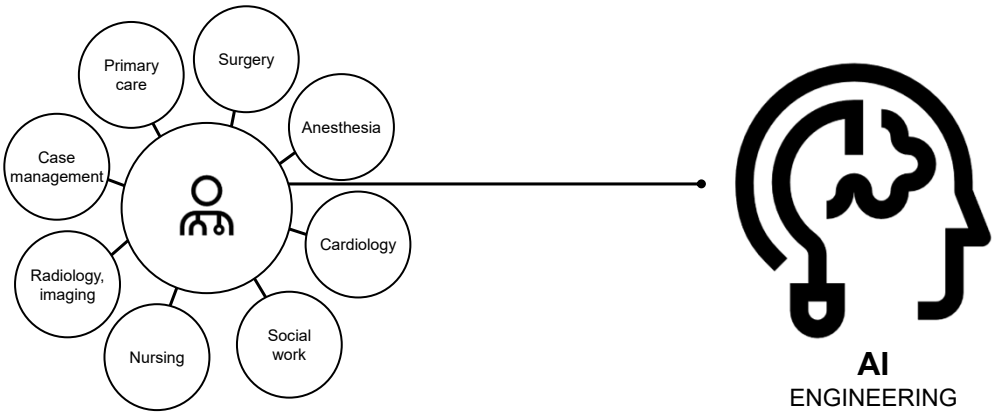
PATIENT-CENTERED CARE

SUCCESS DETERMINED BY THE ENTIRE ECOSYSTEM



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CONCLUSIONS

CLINICAL UTILITY with current workflow

PREDICT AND DETECT disease

Massively **SCALABLE**

Driving practice **INNOVATION**

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QUESTIONS

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